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EXPERIMENTAL STUDIES OF
IONOSPHERIC PROPAGATION
AS APPLIED TO
THE LORAN SYSTEM

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EXPERIMENTAL STUDIES OF IONOSPHERIC PROPAGATION
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I. Introduction

The Loran system, as an aid to navigation, depends upon the determination of the difference in the great-circle distances between the point of observation and two points of known latitude and longitude. By expressing these distances in units of time (microseconds) required for the ground wave to travel from each of two synchronized radio-frequency pulse transmitters to the point of observation, the difference in the distances may be determined by measuring the difference in the time of arrival of the two sets of ground-wave pulses. The Loran system is thus fundamentally a ground-wave system. The difference in the time of arrival of the ground-wave pulses, from the two Loran transmitting stations, is known as the "ground-wave time difference".

The direct determination of ground-wave time differences is limited to the area in which the ground wave from both Loran transmitters can be received sufficiently well to permit time-difference measurements. Pulses reflected from the ionosphere, or "sky-wave" pulses, may be received at distances considerably in excess of the ground-wave range. This condition provides a method by which the usefulness of the system can be extended, under favorable conditions, to distances of approximately 1,400 nautical miles from the farthest transmitting station.

Two types of sky-wave time-difference measurements are practical: (a) the difference in the time of arrival of the first sky wave from one station and the ground wave from the other, and (b) the difference in the time of arrival of the first sky wave from each station.

The time required for a sky wave to travel from the transmitting station up to the ionosphere and back down to the receiving point is greater than that required for a ground wave to travel between the same points. The difference in the time of arrival of the sky-wave pulse and the ground-wave pulse from a single Loran transmitting station is known as the "sky-wave delay." The magnitude of the sky-wave delay is a function of the distance between the transmitting and receiving points and conditions existing in the ionosphere.

In order to represent the difference in the great-circle distance between the Loran transmitting stations and the receiving point, all time-difference measurements involving sky waves must be converted into equivalent ground-wave time differences. The correction necessary for a time-difference measurement between a ground wave and a sky wave is simply the sky-wave delay. The correction for a time-difference measurement between two sky waves is the difference between the two sky-wave delays. These corrections are more fully explained in connection with the use of the sky-wave delay curves.

The purpose of these studies was to determine:

- (a) The reliability with which sky waves, suitable for Loran measurements, can be received at various distances.
- (b) The effective layer heights.
- (c) Reasonable correction values to be applied to time-difference measurements involving sky waves in order to convert them into equivalent ground-wave time differences.
- (d) The variation in sky-wave corrections that may reasonably be expected as a result of changing ionosphere conditions.
- (e) The effect of frequency upon sky-wave Loran propagation.

II. Program of Observations

The program consisted of time-difference measurements, from pulse transmissions, involving ground and sky waves at both vertical and oblique incidence. Most of the measurements were made at the IRPL receiving station at Sterling, Va., near Washington, D.C. Many were made at a temporary observing location at Longport, N.J. A total of 13,774 observations were made during the months of October, November, and December, 1943, and January, 1944. A standard Loran receiver and indicator was used for the reception and measurement of the pulse signals.

Three types of observations were made: (a) low-frequency oblique incidence (660 kc at 387 kilometers); (b) regular Loran-frequency oblique incidence at various distances up to 1500 kilometers, (c) regular Loran-frequency vertical incidence.

Low-frequency (660 kc) observations were made on pulse transmissions from WEAF during October and November, 1943. Special pulsing equipment was furnished to station WEAF by the IRPL for this purpose. The transmissions were made during the first ten minutes of each half hour, beginning at 0030 and ending at 0410 local time. This phase of the program involved measurements of the difference in the time of arrival of the first sky wave and the ground wave. The distance between the transmitting and receiving points was 387 kilometers.

Pulse transmissions were also observed from WLW (700 kc, 591 km) and WQXR (1550 kc, 378 km), using pulse equipment furnished by IRPL for the purpose. However, satisfactory reception of transmissions from WLW was found to be impractical because of interference on adjacent radio frequencies. Excellent reception of sky-wave pulses was obtained from WQXR but the amplitude of the ground-wave pulse, at Sterling, Va., was too small to permit direct measurement of sky-wave delay values.

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Extensive time-difference measurements were made on pulse transmissions from regular Loran stations (1,950 kc) during December, 1943, and January, 1944, at distances ranging from 104 kilometers to 1514 kilometers. All observations have been included in the tabulations and graphs, regardless of the deviation of any single observation from mean or median values.

Three kinds of observations were made on Loran stations: (a) ground-wave observations, (b) ground-sky-wave observations, (c) sky-sky-wave observations.

A ground-wave observation represents the measurement of the difference in time of arrival of the ground wave from each of two Loran stations. These measurements are useful for comparison with the calculated time differences. All ground-wave time-difference measurements were made from the leading edge of one ground-wave pulse to the leading edge of the other.

A ground-sky-wave observation represents the measurement of the difference in the time of arrival of the ground wave from one Loran station and the first sky wave from the other. The sky-wave delay is the difference between this measurement and the ground-wave time difference. All ground-sky-wave time-difference measurements were made from the leading edge of the ground-wave pulse of one station to the leading edge of the first sky-wave pulse of the other station.

A sky-sky-wave observation represents the difference in the time of arrival of the first sky wave from each of two Loran transmitting stations. The difference between this measurement and the ground-wave time difference is known as the "sky-wave correction" and is the difference between the sky-wave delays of the two signals. All sky-sky-wave time-difference measurements were made from the leading edge of the first sky-wave pulse of one station to the leading edge of the first sky-wave pulse of the other station.

Random measurements, of the types mentioned above, were made on three pairs of Loran stations, as follows:

<u>Station</u>	<u>Distance in km</u>	<u>Pair Number</u>
A	218	
B	689	
C	1123	
D	1514	
		0
		1
		2

These observations were made at the IRPL receiving station, Sterling, Va., between 0830 and 1530 local time.

Two sets of continuous ground-sky-wave observations were maintained, at the rate of one measurement per minute, over a 24-hour period, for each of three distances as follows:

<u>Receiving Location</u>	<u>Distance to Transmitting Station in km</u>	<u>Date</u>
Sterling, Va.	689	28-29 Dec., 1943
" "	689	29-30 Dec., 1943
Longport, N.J.	442	18-19 Jan., 1944
" "	442	20-21 Jan., 1944
" "	885	19-20 Jan., 1944
" "	885	21-22 Jan., 1944

Random ground-wave observations were made at Longport, N.J., for comparison with calculated time differences.

Measurements of sky-wave delay (1,950 kc) at vertical incidence were made at the National Bureau of Standards radio receiving station, Sterling, Va., during December, 1943.

III. Discussion of Results

A. Low-Frequency Oblique-Incidence

Low-frequency pulse transmissions (660 kc) from WEAF were received, at Sterling, twenty-four nights during October and November, 1943. Sky waves were present at all times during the observational period, 0030 to 0410 local time.

A typical pulse pattern, as observed during this program, is illustrated in Fig. 1.

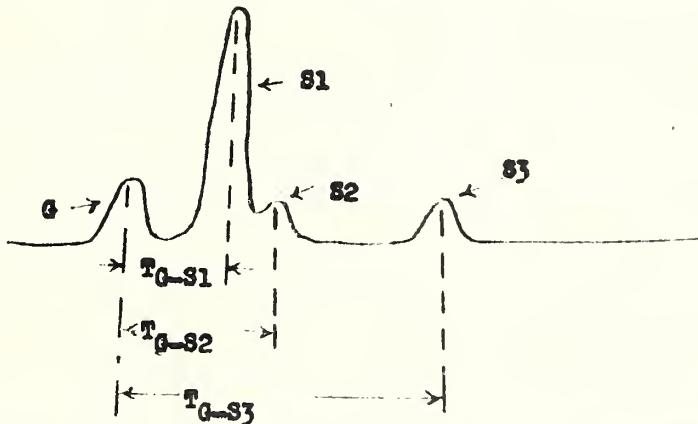


Fig. 1. Typical pulse pattern received from WEAF.

The ground-wave pulse is designated "G". S₁, S₂, and S₃ represent the first, second, and third sky waves. T_{G-S1} represents the difference in the time of arrival of the ground wave and the first sky wave, T_{G-S2} the time difference between the ground wave and the second sky wave and T_{G-S3} the time difference between the ground wave and the third sky wave. An example of typical time differences (measured values at 0135-0136 local time, 11 November, 1943) follows:

T _{G-S1} :	140 microseconds
T _{G-S2} :	227 "
T _{G-S3} :	527 "

Equivalent reflection heights for these time differences, with an assumed sky-wave velocity of 3×10^8 meters/second over a triangular path, are as follows:

First sky wave:	89.7 kilometers
Second sky wave:	116.8 "
Third sky wave:	189.1 "

The number of sky-wave pulses received varied from one to six, with three the number most often observed. The amplitude of the first sky wave was almost invariably the largest, usually much larger than the ground wave. Most time-difference measurements were made on the first sky wave, with reference to the ground wave.

A rough correlation was observed between the amplitude of the first sky wave and its sky-wave delay. Low sky-wave field intensities were accompanied by small values of sky-wave delay, indicating low equivalent reflection heights.

The distribution of sky-wave delay observations (number of observations vs sky-wave delay) for all measurements of the first sky wave from WMAF (660 kc) is illustrated in Fig. 2. A scale of equivalent reflection height for a triangular path with a constant velocity of 3×10^8 meters/second is indicated below the sky-wave delay scale.

Fig. 3 shows the average and extreme values of equivalent reflection height for the first ten minutes of each half hour for the observational period 0030 to 0410 local time.

The probable error in the measurement of a single observation is estimated to be within ± 3 microseconds. The wide range of sky-wave delay values (107 to 177 microseconds) represents changes in the ionosphere.

B. Regular Loran-Frequency Oblique Incidence

A summary of the ground-wave observations made at Sterling, Va., between 8 December 1943 and 14 January 1944 is shown in Table 1.

The first number in the Loran reading identifies the Loran stations from which the measurement is made. All ground-wave observations at Sterling were made from the "0" pair of transmitting stations. Most of the observations within the range of 01216 to 01221 were obtained during the period between 4 January 1944 and 11 January 1944. These deviations from the calculated value are believed to represent errors in synchronization of the Loran stations or errors in measurement at the receiving point. The median value, 01211, is believed to be nearer the correct ground-wave time-difference than the average. Calculated values are obtained from the difference in the distances to the transmitting stations.

Summaries of ground-wave observations made at Longport, N.J., between 18 January 1944 and 22 January 1944 are shown in Tables 2 and 3.

Table 1. Ground-Wave Observations, Sterling, Va.

<u>Loran Ground-Wave Reading in Microseconds</u>	<u>Number of Observations</u>
01202	2
01203	2
01206	4
01207	4
01208	13
01209	52
01210	138
01211	178
01212	114
01213	51
01214	38
01215	26
01216	11
01217	22
01218	23
01219	38
01220	19
01221	6
01222	2
	743

Average ground-wave time difference, 01212.3.

Median ground-wave time difference, 01211.

Calculated ground-wave time difference, 01210.6.

Table 2. Ground-Wave Observations, Longport, N.J.

Loran Ground-Wave Reading in Microseconds	Number of Observations
01642	2
01645	13
01646	5
01647	25
01648	127
01649	281
01650	205
01651	64
01652	15
01653	2
01654	1
	740

Average ground-wave time difference, 01649.2

Median ground-wave time difference, 01649

Calculated ground-wave time difference, 01647.8

Table 3. Ground-Wave Observations, Longport, N.J.

Loran Ground-Wave Reading in Microseconds	Number of Observations
13901	1
13902	3
13904	1
13905	1
13907	2
13908	10
13909	23
13910	54
13911	60
13912	29
13913	14
13914	6
13915	4
13916	1
13917	3
13918	2
13919	2
13920	1
	217

Average ground-wave time difference, 13910.8

Median ground-wave time difference, 13911

Calculated ground-wave time difference, 13911.0

The small amount of scatter in the ground-wave measurements as shown in Table 2, relative to the other two groups, is believed to be due to more favorable ground-wave field intensities obtained for these observations.

On the basis of the distribution of ground-wave observations, it is believed that ± 2 microseconds is a reasonable probable error for a single observation, and ± 15 microseconds is a reasonable maximum error to be expected from a single observation as a result of errors in synchronization at the transmitting stations and measurement at the receiving point.

Loran sky-wave observations were made on 1,950 kilocycles during December 1943 and January 1944, at all hours of the day and night and at distances of 104, 218, 442, 689, 885, 1123, and 1514 kilometers from the transmitting stations.

The amplitude of the sky waves was much greater at night, regardless of distance, than during the day. The weakest sky waves were usually observed during the middle of the day. Wide changes in amplitude and shape of the sky waves were observed from minute to minute, particularly at night, and from one day to the next. Low sky-wave delay values, representing low equivalent reflection heights, were characteristic of low sky-wave amplitudes, as was noted during the WEAF observations.

During the day the Loran sky-wave pulse patterns normally represented only one reflection. However, at night the sky-wave patterns were very complex, changing rapidly in shape and amplitude. It was often impossible to distinguish the point at which the first sky wave ended and the second began. A train of sky waves, consisting of dozens of components, covering a sky-wave delay range up to 10,000 microseconds, was not at all unusual. The complexity of the sky-wave patterns appeared to vary inversely with the distance from the transmitting stations.

Sky waves from the Loran station located 689 kilometers from the point of observation were always present, regardless of the time of day. Sky waves from the stations located 218, 442, 885, and 1123 kilometers from the point of observation were normally present at all hours of the day. Sky waves from the station located 1514 kilometers from the point of observation were always present at night and about fifty percent of the time at all hours of the day.

Three sets of continuous sky-wave delay observations were made, at the rate of one time-difference measurement per minute, over two 24-hour periods each, at distances of 442, 689, and 885 kilometers, for the purpose of observing any diurnal change in sky-wave delay. The average and extreme values, for each 20-minute period, obtained from this program are shown in Figs. 4 to 9. The sky-wave delay for each observation, plotted against local time, is shown in Figs. 10 to 33.

It will be observed that the sky-wave delay was normally less during the day than at night. However, on 29 December 1943, from 0440 to 0620 (Fig. 4), and on 21 January 1944, from 0040 to 0140 (Fig. 8), sky-wave delay values were obtained comparable to those normally measured during the daytime. An abrupt increase in sky-wave delay at or near sunrise was observed on four of the six days of continuous observation.

The values obtained from the continuous observational program have been divided into four groups, based upon the time of observation, as follows:

- (a) Daytime observations, covering the period 0900 to 1500 local time.
- (b) Sunset observations, covering the period 1500 to 2100 local time.
- (c) Nighttime observations, covering the period 2100 to 0300 local time.
- (d) Sunrise observations, covering the period 0300 to 0900 local time.

The distribution of sky-wave delay observations (number of observations vs sky-wave delay) for each of the above time periods is shown in Figs. 34 to 36.

The distribution of sky-wave delay measurements, made at random during the day, between 8 December 1943 and 14 January 1944 are shown in Figs. 37 and 38. These measurements were made at distances of 218, 689, and 1123 kilometers from the transmitting stations.

The distribution of sky-wave correction observations, made at random during the day, from 8 December 1943 to 14 January 1944, is shown in Fig. 40. These observations represent time-difference measurements involving only sky waves. The sky-wave correction is the difference between the sky-wave delay of each signal and therefore involves the distance from each transmitting station.

The sky-wave delay curve represents the sky-wave delay as a function of distance from the transmitting station. Points, by which this curve may be determined graphically, are obtained from sky-wave delay measurements which represent the height of the delay curve at each observational distance. The daytime delay curve, illustrated in Fig. 39, was derived in this manner from the average and median values of all daytime sky-wave delay measurements.

A sky-wave correction is the difference between the sky-wave delays from two transmitting stations and therefore represents the average slope of the delay curve between the two distances. The sky-wave delay curve may thus be extended, beyond distances at which the sky-wave delay

can be directly measured, by use of sky-wave correction observations.

Fig. 41 contains the daytime sky-wave delay curve, previously described, with points representing the mean and median of all sky-wave corrections observed at distances of 218-589, 689-1123, and 1123-1514 kilometers from transmitting stations.

Fig. 42 contains the sky-wave delay curve, derived by the Bureau of Ships, Navy Dept., for determination of Loran sky-wave corrections. The mean, median, and extreme values of nighttime sky-wave delay obtained from the continuous observational program are also shown in this Fig. The ranges of observed values are shown by the three vertical lines. As shown, the mean and median observed nighttime values agree well with this curve. (For daytime values see Fig. 39). Fig. 42 is believed to represent values of sky-wave delay that may reasonably be expected under nighttime ionosphere conditions.

The purpose of the sky-wave delay curve is to enable the observer to convert a Loran time-difference measurement, involving sky waves, into an equivalent ground-wave time difference. The method by which this may be accomplished will be briefly explained.

Consider a ground-wave measurement as illustrated in Fig. 43.

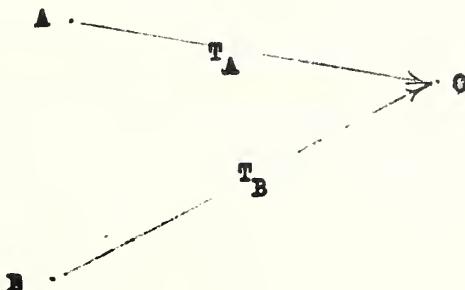


Fig. 43.

"A" and "B" represent two Loran transmitting stations and "O" the point of observation. T_A represents the time, in microseconds required for a ground-wave pulse to travel from A to O and T_B the time, in microseconds, for the ground-wave pulse to travel from B to O. If the transmitting stations are so synchronized that the pulses from B are transmitted exactly β microseconds later than those from station A, the measured ground-wave time difference (T_{AG-BG}) will be as follows:

$$T_{AG-BG} = \beta + T_B - T_A$$

This relation, for ground-wave time differences, holds regardless of the position of O with respect to A and B and therefore regardless of the relative magnitudes of T_A and T_B .

Sky-wave time-difference measurements are illustrated in Fig. 44.

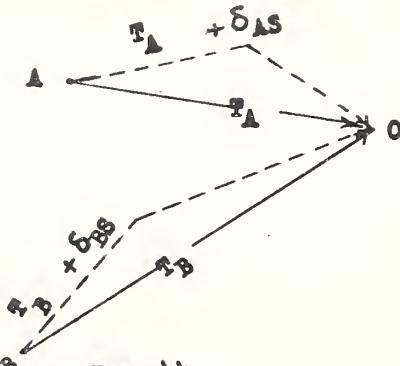


Fig. 44.

$T_A + \delta_{AS}$ represents the time required for the sky-wave pulse to travel from station A to O. Thus δ_{AS} is the sky-wave delay from station A. $T_B + \delta_{BS}$ represents the time required for the sky-wave pulse from station B to travel to O, and δ_{BS} is the sky-wave delay from station B.

The three sky-wave measurements possible under this condition are:

(a) T_{AG-BS} , which represents the difference in the time of arrival of the ground wave from station A and the sky wave from station B. The measured value at O will be:

$$\begin{aligned} T_{AG-BS} &= \beta + (T_B + \delta_{BS}) - T_A \\ &= (\beta + T_B - T_A) + \delta_{BS} \\ &= T_{AG-BG} + \delta_{BS} \end{aligned}$$

(b) T_{AS-BG} , which represents the difference in the time of arrival of the ground-wave from station B and the sky wave from station A. The measured value at O will be:

$$\begin{aligned} T_{AS-BG} &= \beta + T_B - (T_A + \delta_{AS}) \\ &= (\beta + T_B - T_A) - \delta_{AS} \\ &= T_{AG-BG} - \delta_{AS} \end{aligned}$$

(c) T_{AS-BS} , which represents the difference in the sky waves from each station. The measured value at 0 will be :

$$\begin{aligned}T_{AS-BS} &= \beta + (T_B + \delta_{BS}) - (T_A + \delta_{AS}) \\&= (\beta + T_B - T_A) + (\delta_{BS} - \delta_{AS}) \\&\approx T_{AG-BG} + (\delta_{BS} - \delta_{AS})\end{aligned}$$

It will be observed that the magnitude of the correction applicable in cases (a) and (b), in order to obtain an equivalent ground-wave time difference, is the sky-wave delay. This value is obtained directly from the sky-wave delay curve and is a function of distance from the transmitting station. The sign of this type correction depends upon the relative distances from the transmitting stations.

The magnitude of the correction applicable in case (c) is the difference between the sky-wave delays of stations A and B. These values may also be obtained from the sky-wave delay curve. As in the previous cases, the sign of this correction depends upon the relative distances from the transmitting stations. It is believed that this is the only type sky-wave observation that is being used in the Loran system, at the present time. It will therefore be termed the "sky-wave correction".

The sky-wave delay, as obtained from the sky-wave delay curves, must be considered only as a reasonable value. In practice wide variations in sky-wave delay are observed. An estimate of the variation that may reasonably be expected can be obtained from the distribution of sky-wave delay observations illustrated in Figs. 34 to 36 and from Tables 4, 5, and 6.

Table 4. Daytime Continuous Sky-Wave Delay Observations

Distance from transmitting station, in kilometers	442	689	885
Sky-wave delay obtained from delay curve, in microseconds	118	78	66
Range of 50% of observations in microseconds	109 to 122	81 to 82	61 to 68
Total range of observations in microseconds	90 to 138	71 to 91	49 to 75

Table 5. Daytime Random Sky-Wave Delay Observations

Distance from transmitting station, in kilometers	218	689	1,123
Sky-wave delay obtained from delay curve, in microseconds	243	78	59
Range of 50% of observations in microseconds	226 to 256	62 to 81	50 to 67
Total range of observations in microseconds	145 to 314	41 to 99	19 to 105

Table 6. Nighttime Continuous Sky-Wave Delay Observations

Distance from transmitting station, in kilometers	442	689	885
Sky-wave delay obtained from delay curve, in microseconds	144	96	80
Range of 50% of observations, in microseconds	141 to 150	91 to 101	79 to 86
Total range of observations, in microseconds	109 to 181	73 to 113	71 to 98

If the sky-wave delay from one Loran station varies independently from the sky-wave delay of the other, somewhat wider variations in the sky-wave correction would be expected for a Loran time-difference measurement between two sky waves than for either of the sky-wave delays separately. However, the observed sky-wave correction values, made during the daytime, have approximately the same range of values as the corresponding sky-wave delay measurements made during the same period.

The distribution of sky-wave correction values obtained from daytime sky-wave time-difference measurements, for three pairs of Loran stations, is shown in Fig. 40.

Alternate measurements of sky-wave delay were made, for short periods, on stations at distances of 104 and 442 kilometers and at 689 and 885 kilometers. Equivalent reflection heights were determined from the sky-wave delay values and plotted against time of day. Figs. 45 and 46 contain this information.

Fig. 47 shows the daytime equivalent reflection height for a triangular sky-wave path and an assumed velocity of 3×10^8 meters per second, at distances of 150 to 1300 kilometers between transmitting and receiving points. These are the equivalent reflection heights for the daytime sky-wave delay values of Fig. 39.

The nighttime equivalent reflection height, for distances of 400 to 1300 kilometers between transmitting and receiving points, which correspond with the nighttime sky-wave delay values of Fig. 42, are shown in Fig. 48.

C. Regular Loren-Frequency Vertical Incidence

Measurements of vertical-incidence pulse transmissions were made at a frequency of 1,950 kc. The virtual heights obtained ranged between 98 and 130 kilometers and were in substantial agreement with the regular vertical-incidence ionosphere records made during the same period at Sterling.

A thorough discussion of the relationship between vertical-incidence ionosphere measurements and oblique-incidence sky-wave transmission is contained in the paper, The relation of radio sky-wave transmission to ionosphere measurements, by N. Smith, Proc. I. R. E. 27, 332; May 1939. On the basis of simple theory, it is shown that the virtual height of reflection, measured at vertical incidence, for a radio frequency f , is equal to the height of the equivalent triangular path for a higher frequency f' , at oblique incidence. An approximate relation between these frequencies, corrected for the curvature of the earth, is given as follows:

$$f = f' \cos \phi_0 \left[1 - \frac{Z_v' - Z_0}{R + h} \tan^2 \phi_0 \right]$$

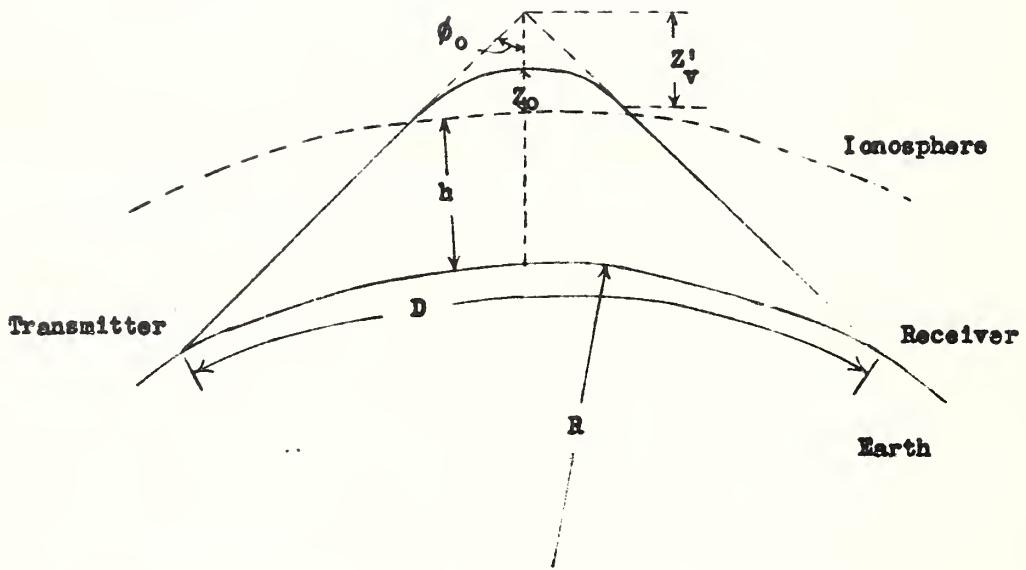
Where: the angle ϕ_0 and distances R , h , Z_v' , and Z_0 are those indicated in Fig. 49.

This approximation leads to results good to 1 percent or better for E-layer transmission, where Z_v' is less than 50 kilometers.

Equivalent vertical-incidence frequencies, calculated from this relationship, for the daytime oblique-incidence observations made on 1,950 kc are shown in Table 7.

Equivalent vertical-incidence frequencies, calculated from the nighttime oblique-incidence data, are shown in Table 8.

The equivalent reflection heights are plotted against equivalent vertical-incidence frequency, for day and night conditions, in Figs. 50 and 51.



D = distance of transmission, R = radius of the earth, Z' = height of equivalent triangular path in the ionosphere, Z_0 = true height of reflection in the ionosphere, h = minimum height of ionosphere above the earth, ϕ_0 = one half-vertex angle of the equivalent triangular path.

Fig. 49.

Table 7. Daytime Equivalent Vertical-Incidence Frequency for 1950-kc Oblique-Incidence Transmissions.

Distance between Receiving and Transmitting Points, Kilometers		Total Height of Equivalent Tri- angular Path in Kilometers ($h + z'$)	Equivalent Vertical- Incidence Frequency, kc
<u>Continuous Observations</u>			
442	average	85.6	721
442	median	86.5	727
689	average	84.1	498
689	median	83.5	495
885	average	79.8	397
885	median	80.5	399
<u>Random Observations</u>			
219	average	94.8	1279
219	median	96.1	1289
689	average	78.5	474
689	median	78.8	476
1123	average	78.8	340
1123	median	78.8	340

Table 8. Nighttime Equivalent Vertical-Incidence Frequency for 1950- kc Oblique-Incidence Transmissions.

Distance between Receiving and Transmitting Points, Kilometers		Total Height of Equivalent Triangular Path in Kilometers ($h + z'$)	Equivalent Vertical-Incidence Frequency, kc
442	average	97.6	806
442	median	97.9	807
689	average	91.4	537
689	median	91.4	537
885	average	91.6	445
885	median	90.5	441

The equivalent vertical-incidence frequency for the WEAF observations, on 660 kc , is 286 kc and the equivalent reflection height is 90.5 kilometers. These values represent the mean of all observations on 660 kc .

Vertical-incidence ionosphere measurements, in the range of 250 to 800 kc , are not, as yet, available for checking the virtual height of the equivalent vertical-incidence frequencies.

IV. Conclusions

Sky-wave propagation, with equivalent reflection layer heights between 60 and 110 kilometers, may be expected from the present Loran transmitting stations on 1,950 kc , at all times of the night, and approximately fifty percent of the time during the day, at distances of 400 to 1,500 kilometers. The maximum night distance is probably around 2,500 kilometers.

Data on the ionosphere layer heights effective in Loran propagation under various conditions and at various times of day are given in the attached Figs.

Correction values for Loran sky-wave observations, as a function of distance from the transmitting stations, may be obtained from the sky-wave delay curves of Figs. 39 and 42, which correspond to the equivalent reflection heights of Figs. 47 and 48.

Wide variations in sky-wave correction values, from those recommended, may be expected in practice. The most consistent sky-wave delay, or correction, values will be obtained between the hours of 2100 and 0300 local time, and the most erratic will be at or near sunrise and sunset.

Deviations from the recommended sky-wave delay values up to ± 10 microseconds may be expected at distances from the transmitting stations of 500 kilometers or greater, but the probability of a single Loran sky-wave measurement falling within this range is dependent upon the time of day and the particular day on which the observation is made as well as the distance from the transmitting stations. Under unusual ionospheric conditions, the recommended sky-wave delay values may be in error by as much as 50 microseconds.

It appears that substantial advantages can be gained by the use of lower radio frequencies than 1,950 kc, because of simpler sky-wave pulse forms, less variation in sky-wave correction values, and greater ground-wave distance range.

V. Further Work Needed

The following subjects, in approximate order of urgency, should be studied. They will be pursued as fully as practicable.

- (a) Diurnal variation in sky-wave correction values. This will involve continuous measurements, over at least 24-hour periods, of the time difference between sky waves from both stations in a Loran pair.
- (b) Alternate measurements of the sky-wave delay from two Loran stations. This information will show the extent to which the equivalent reflection height of the two sky-wave paths vary independently.
- (c) Periodic continuous measurements of sky-wave delay, for the purpose of determining any seasonal trend in equivalent reflection height.
- (d) Measurement of virtual height at equivalent vertical-incidence frequencies. If these measurements check the values indicated by the Loran oblique-incidence measurements, a multi-frequency automatic recording equipment, covering the range of 200 to 600 kilocycles could be used in connection with suitable transmission curves to obtain oblique-incidence transmission information at a minimum of time and expense. If the equivalent vertical-incidence measurements do not check the values indicated by the Loran measurements, oblique-incidence measurements may be made at higher frequencies than 1,950 kc in order to check the accuracy of the transmission curves now being used.
- (e) Measurement of sky-wave delay for an east and west path and for a north and south path, in order to determine the effect of the magnetic field of the earth upon low-layer sky-wave transmission.
- (f) Determination of sky-wave field intensities, for correlation with equivalent reflection heights.
- (g) Determination of sky-wave delay at latitudes other than that of Washington.



9 MAR 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Equivalent Reflection Height vs. Time of Day

23 October 1943 to 21 November 1943

Frequency: 660 kilocycles

Distance: 387 kilometers

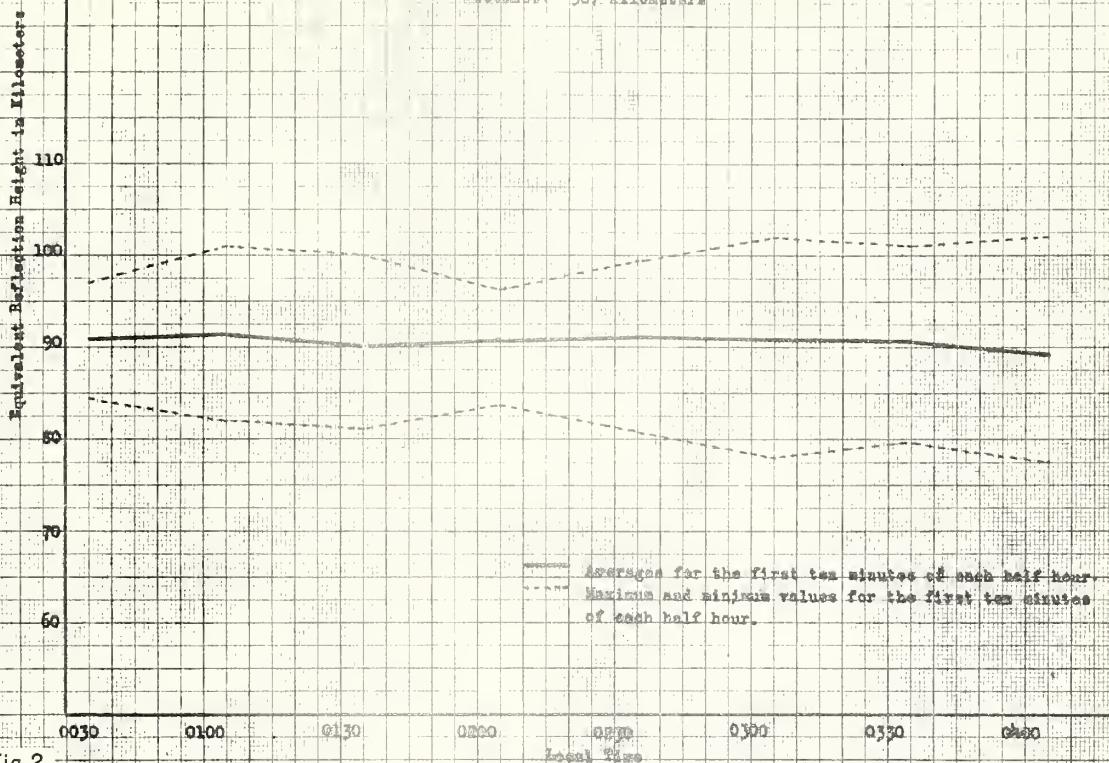


Fig. 2

Distribution of Sky Wave Delay Observations

23 October 1943 to 21 November 1943

Frequency: 660 kilocycles

Distance: 387 kilometers

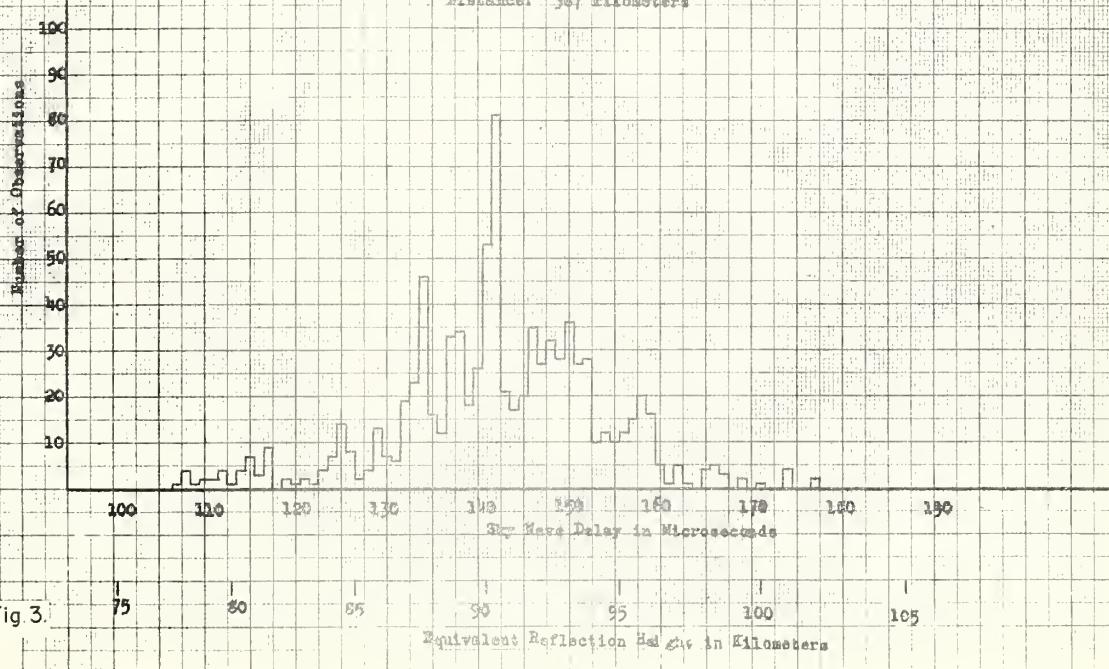


Fig. 3.

7 MAR 1944

INTERSERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.	Wave Delay, sec.	Time of Day
Sterling, Virginia
2100 to 2100 Local Time
25-29 December 1947
Distance: 685 Kilometers
Frequency: 1,950 kilocycles

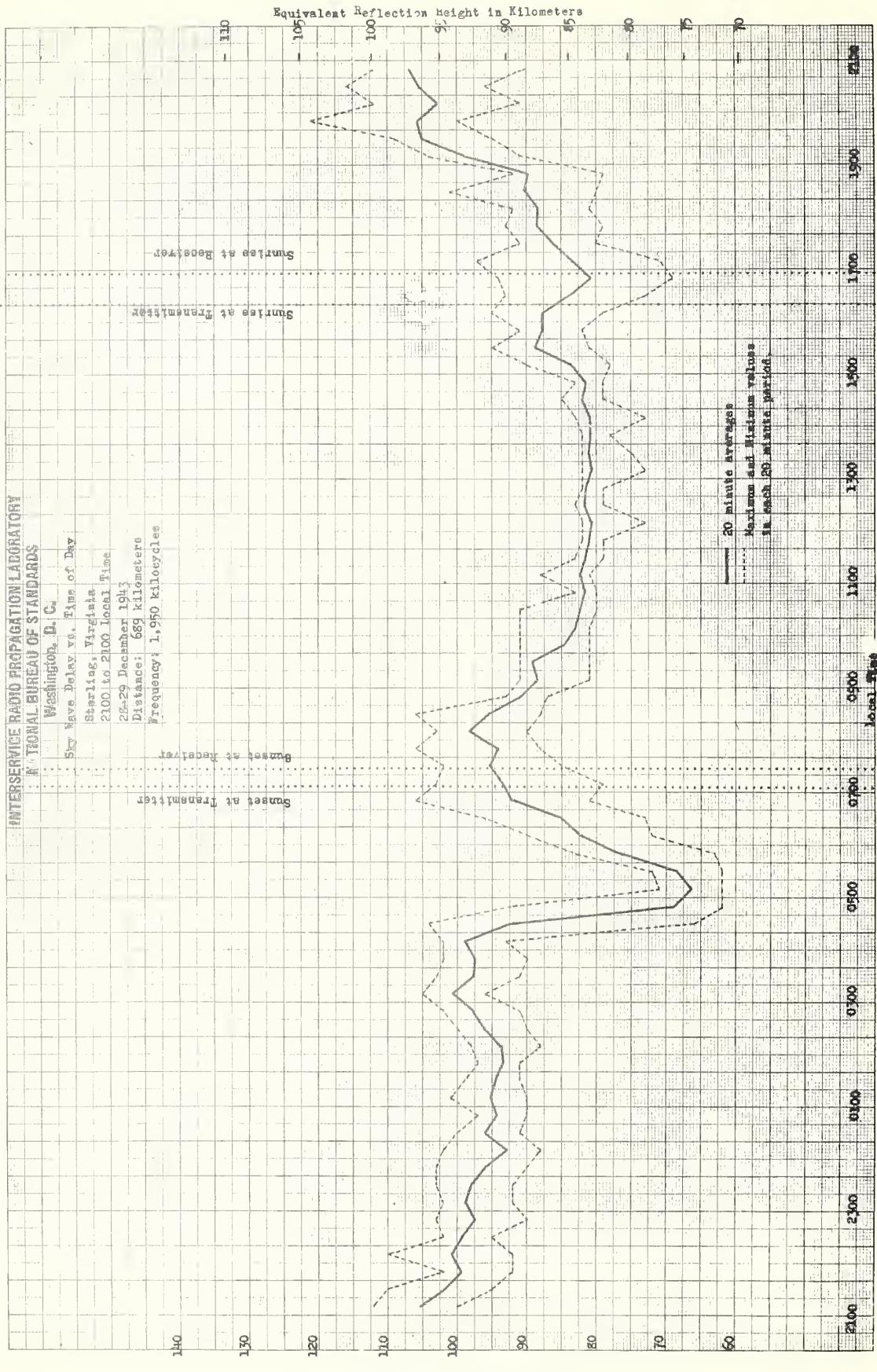


Fig. 4.

7 MAR 1944

WINTER SERVICE IN THE PROPAGATION STATION

Georgian D. C.

1977-1978. *Journal of the Royal Society of Medicine* 71: 625-626.

1997 052 65 2022

200 विद्युत विज्ञान

20. U. S. Presidents

Distance: 39 Kilometers

Fig. 5

7 MAR 1944

WIRELESS PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Wireless Division, Time of Day

Freeport, New Jersey

0900 to 0900 Local Time

18-19 January 1944

Distance: 142 Kilometers

Frequency: 1,990 Kilocycles

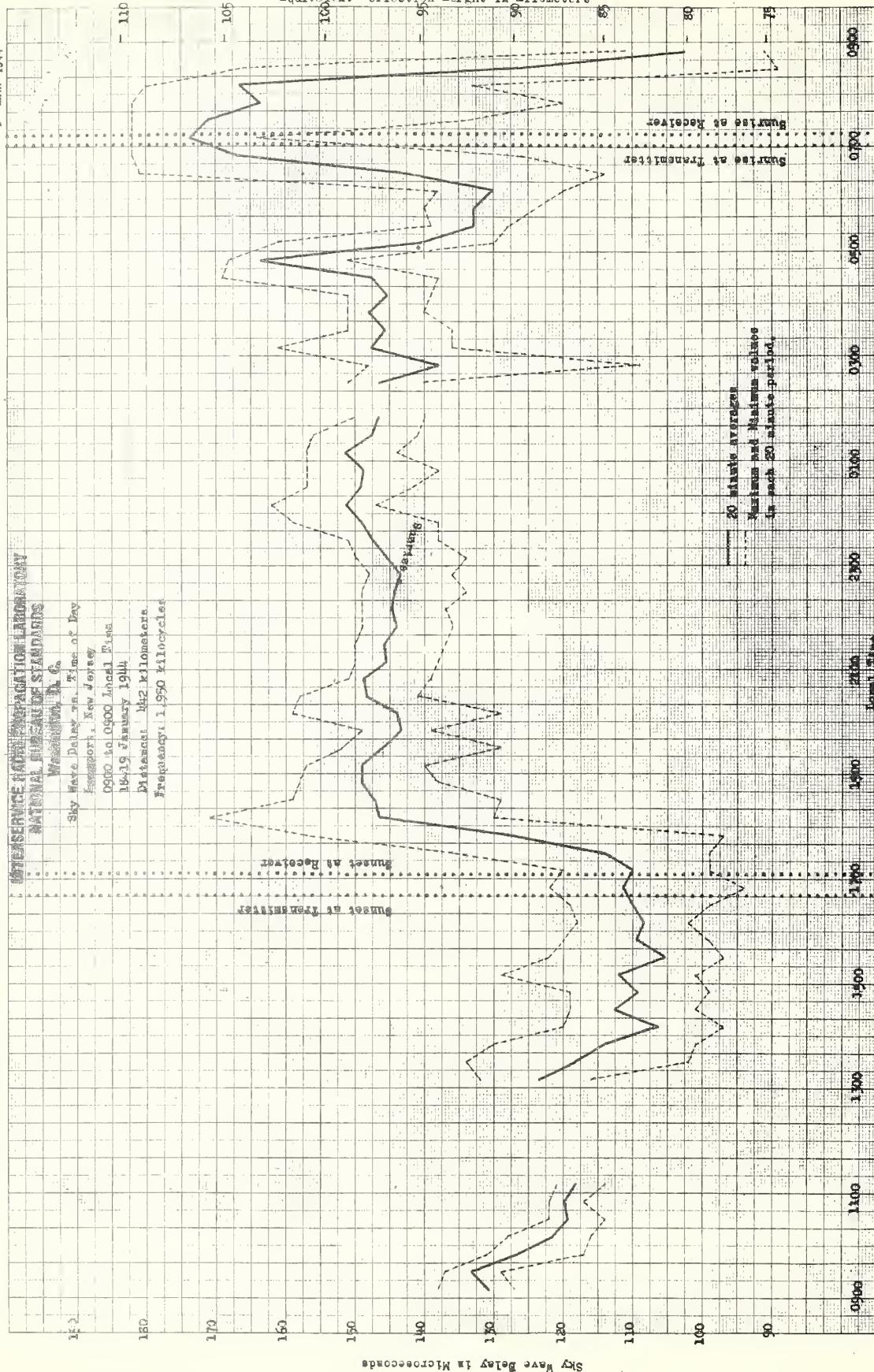


Fig. 6.

9 MAR 1944

TELESERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

City Wave Delay vs. Time of Day
Longport, New Jersey
0200 to 0900 Local Time
1920 January 1944
Distance: 885 Kilometers
Frequency: 1,990 Kilocycles.

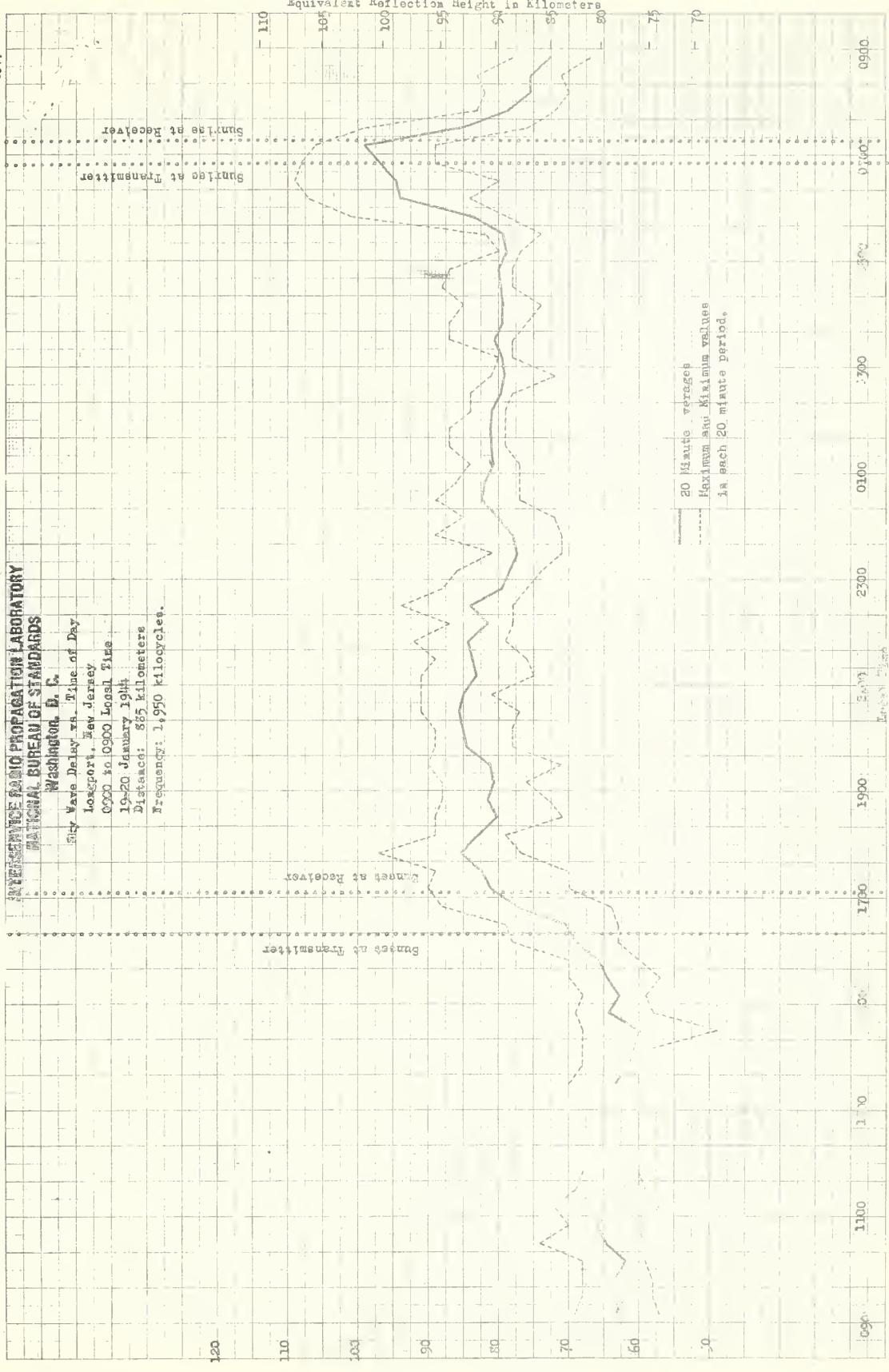


Fig. 7

9 MAR 1944

TELESERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Short Wave Delay vs. Time of Day

Airport, New Jersey

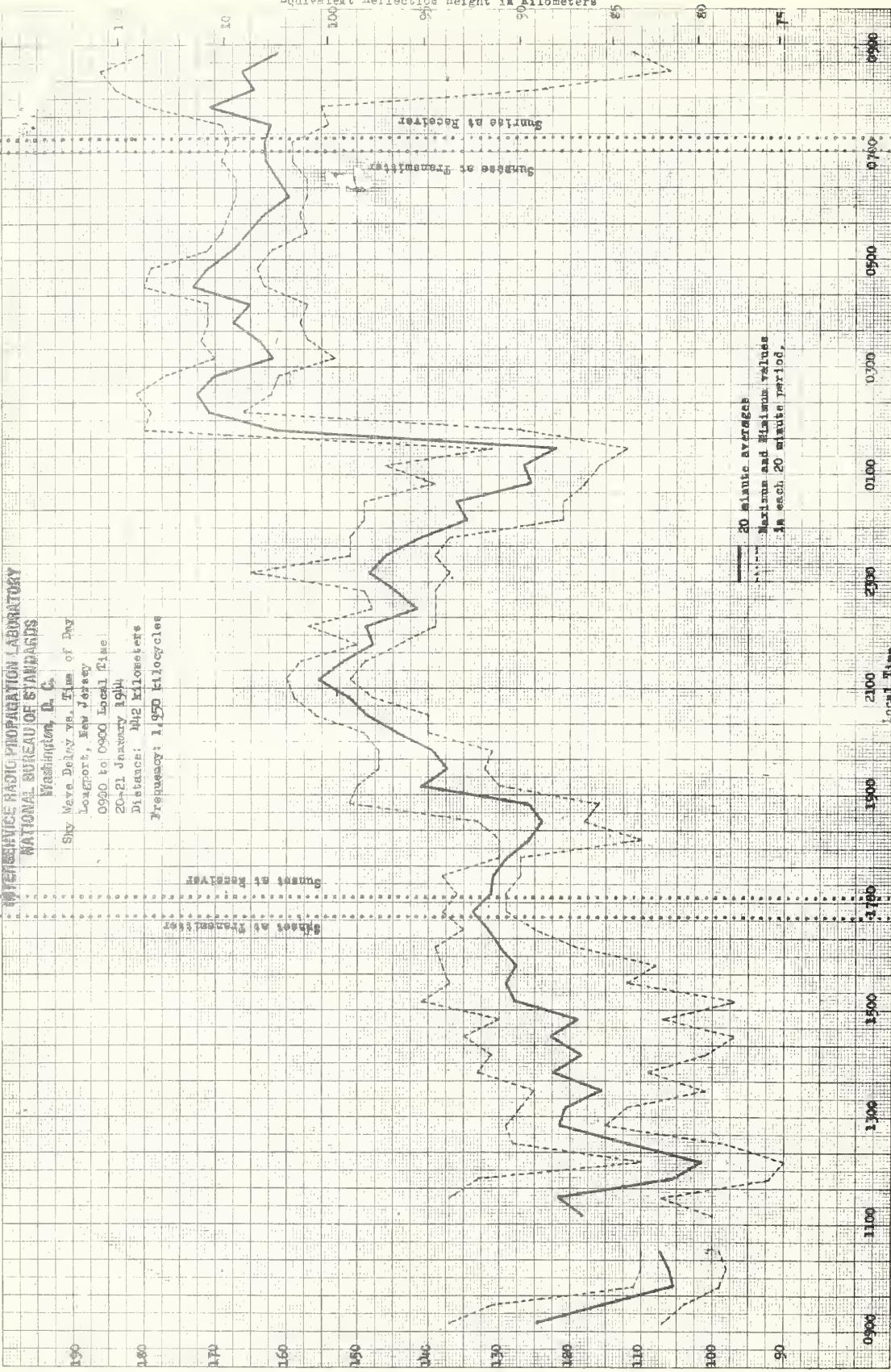
0940 to 0900 Local Time

20-21 January 1944

Distance: 112 Kilometers

Velocity: 1,250 Kilometers

Equivalent Reflection Height in Kilometers



20 minute averages
Maximum and Minimum values
in each 20 minute period,

SKY Wave Delay in microseconds
Local Time

Fig. 8.

7 MAR 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Short Wave Delay - 12 Microseconds

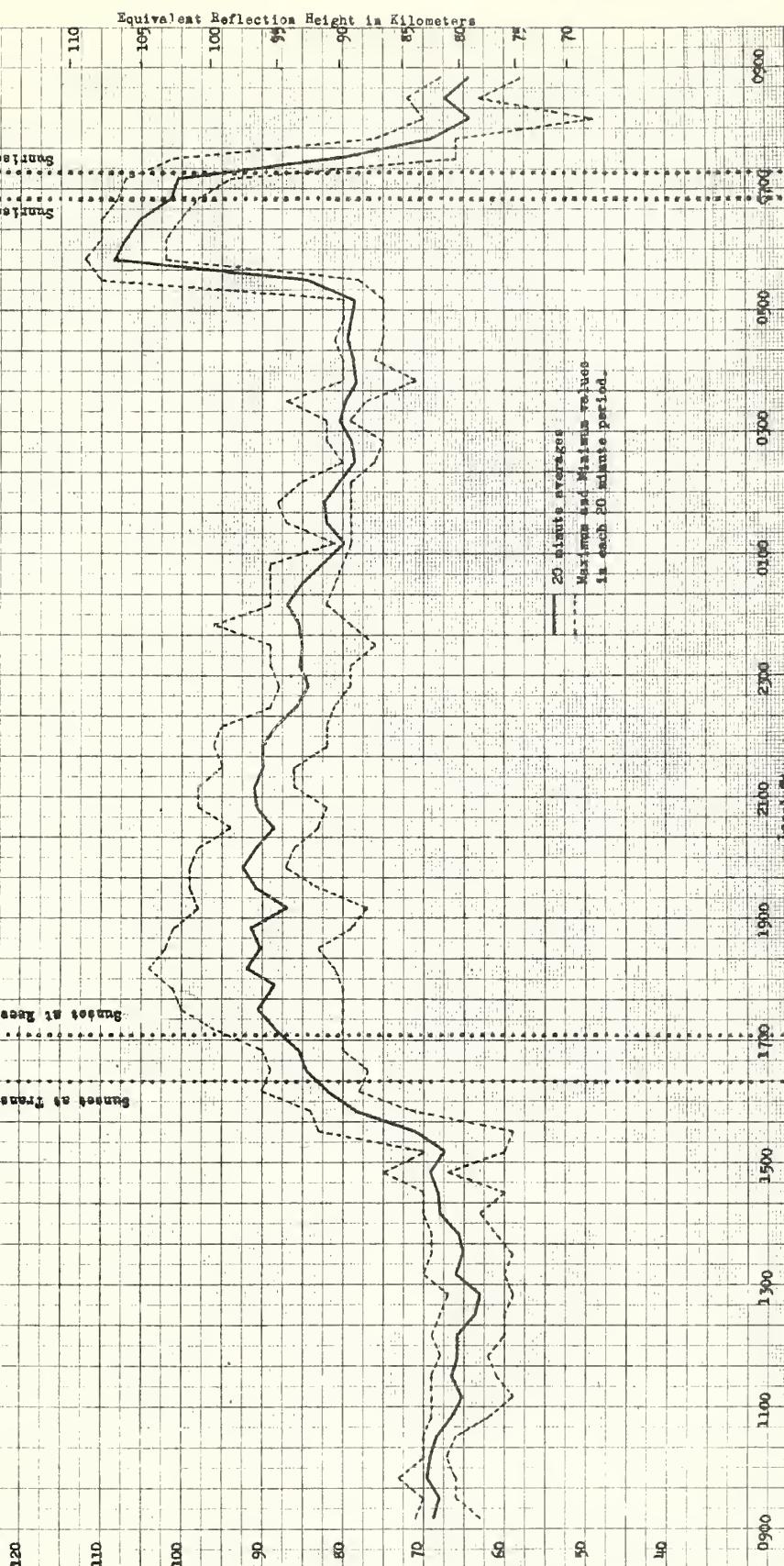
Longport, New Jersey

0900 to 0900 Local Time

21-22 January 1944

Distance: 855 Kilometers

Frequency: 1,950 Kilocycles



Short Wave Delay in Microseconds

Fig. 9.

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

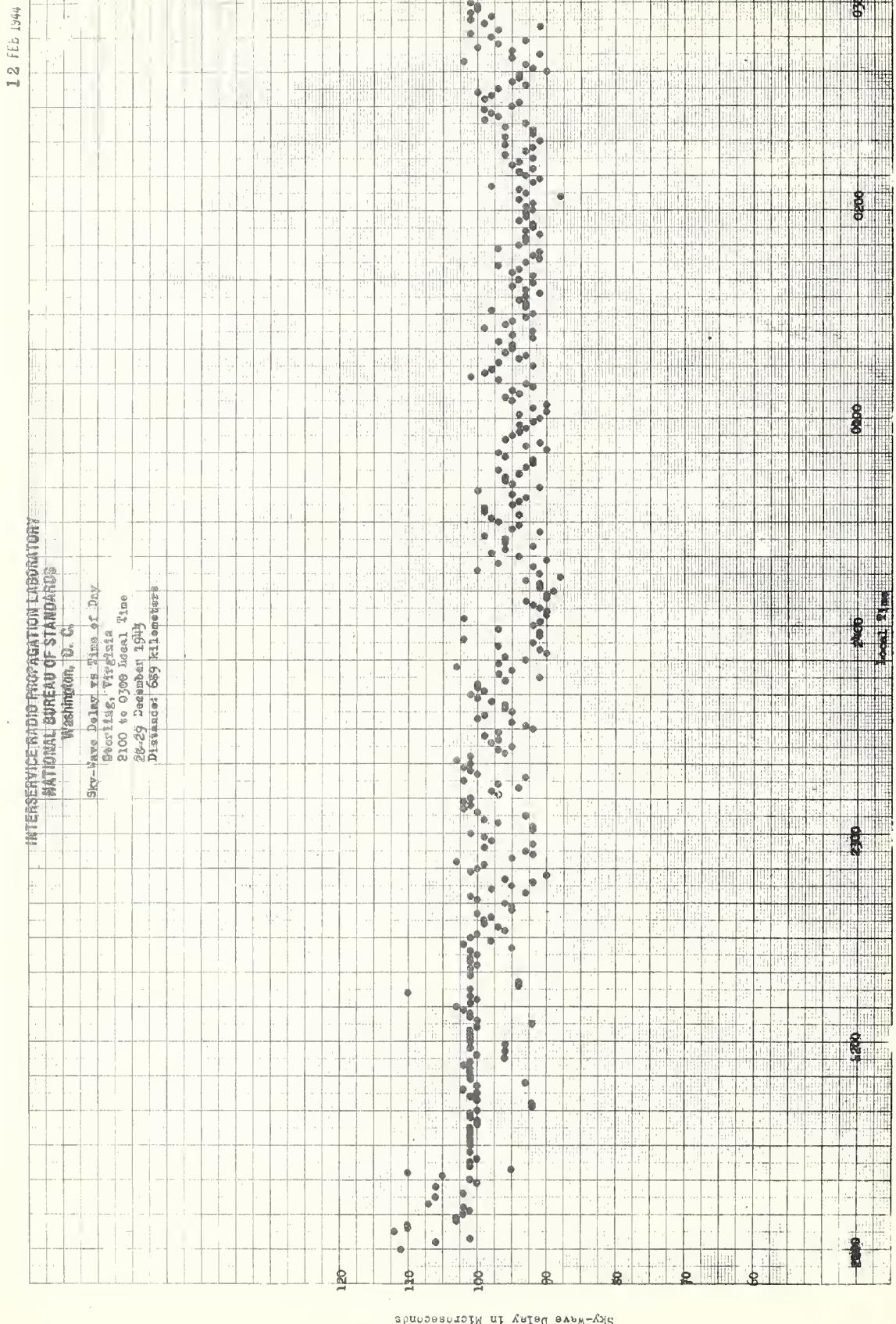


Fig. 10.

12 FEB 1944

INTER-SERVICE RADIOPHONATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Sign-More Delivery to Place of Day
Starting: Virginia
0100 to 0500 Local Time
29 December 1943
Distance: 683 kilometers

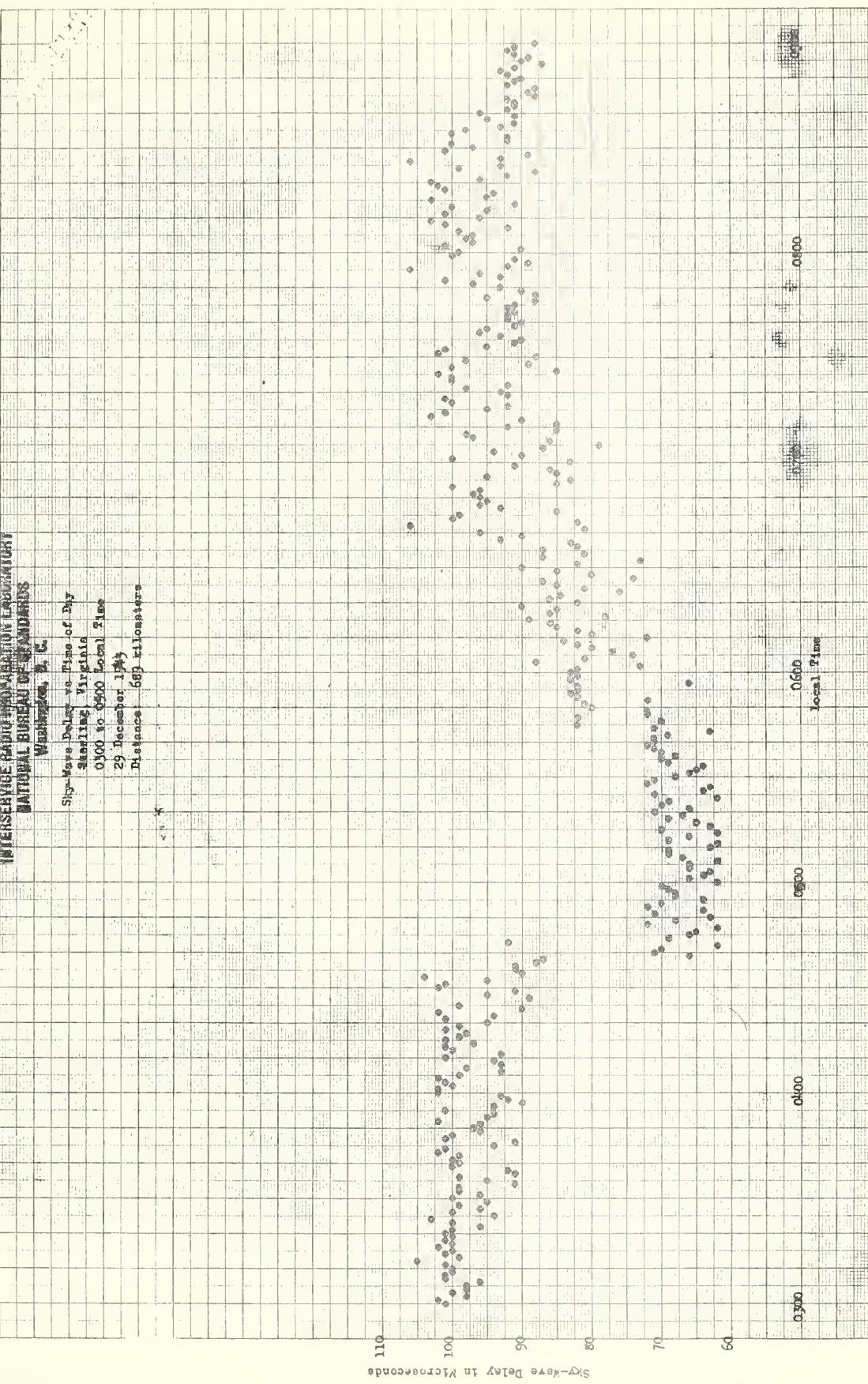


Fig. 11.

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Slow-Maze Delay vs Time of Day
Sterling, Virginia
0900 to 1500 Local Time
29 December, 1947
Distance: 689 Kilometers

12:00 P.M.

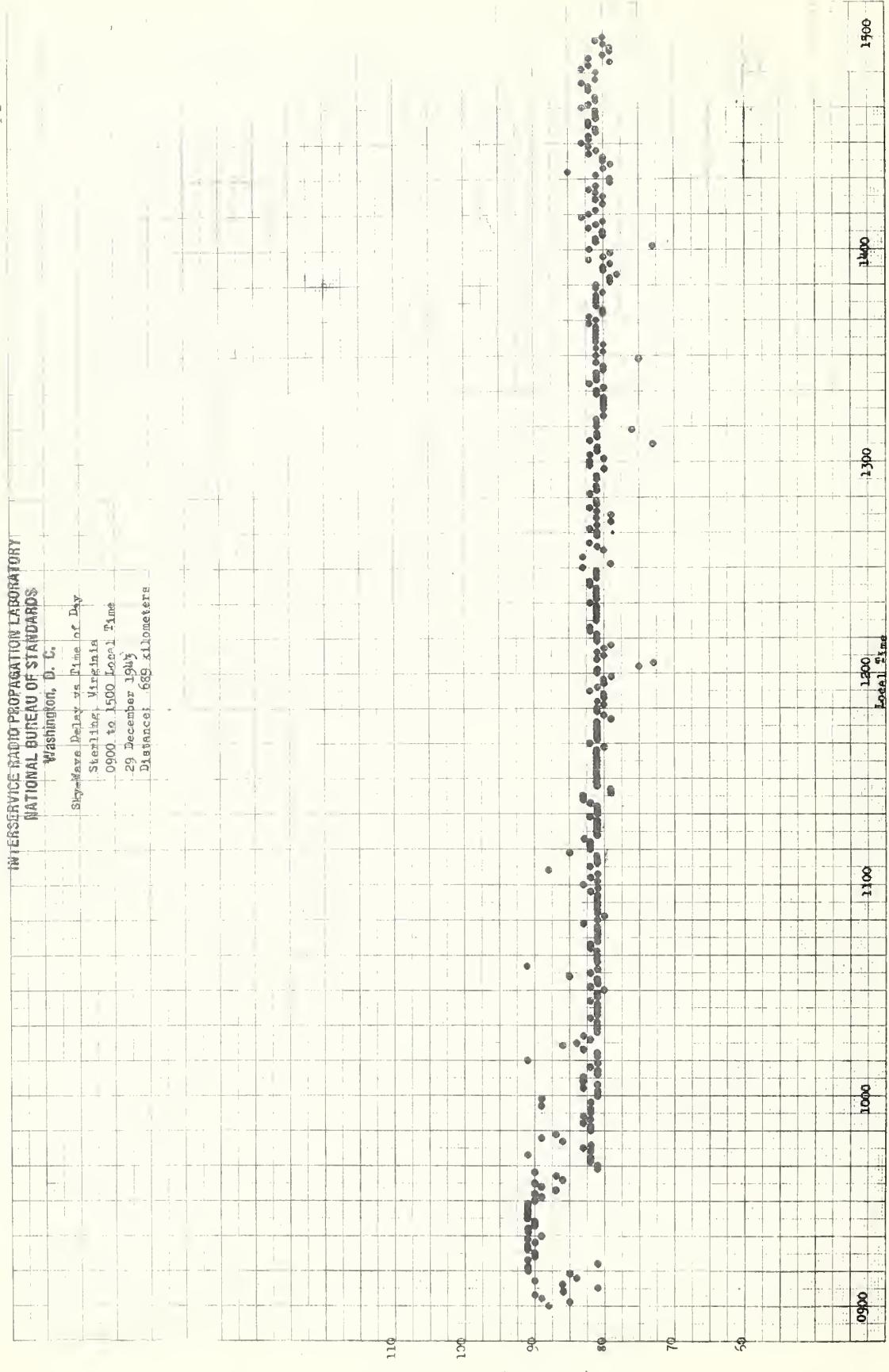


Fig. 12.

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Site Delay vs Time of Day

Shenandoah, Virginia

1600 AM 2100 Local Time

PS 3, November 1943

Distance: 659 Kilometers

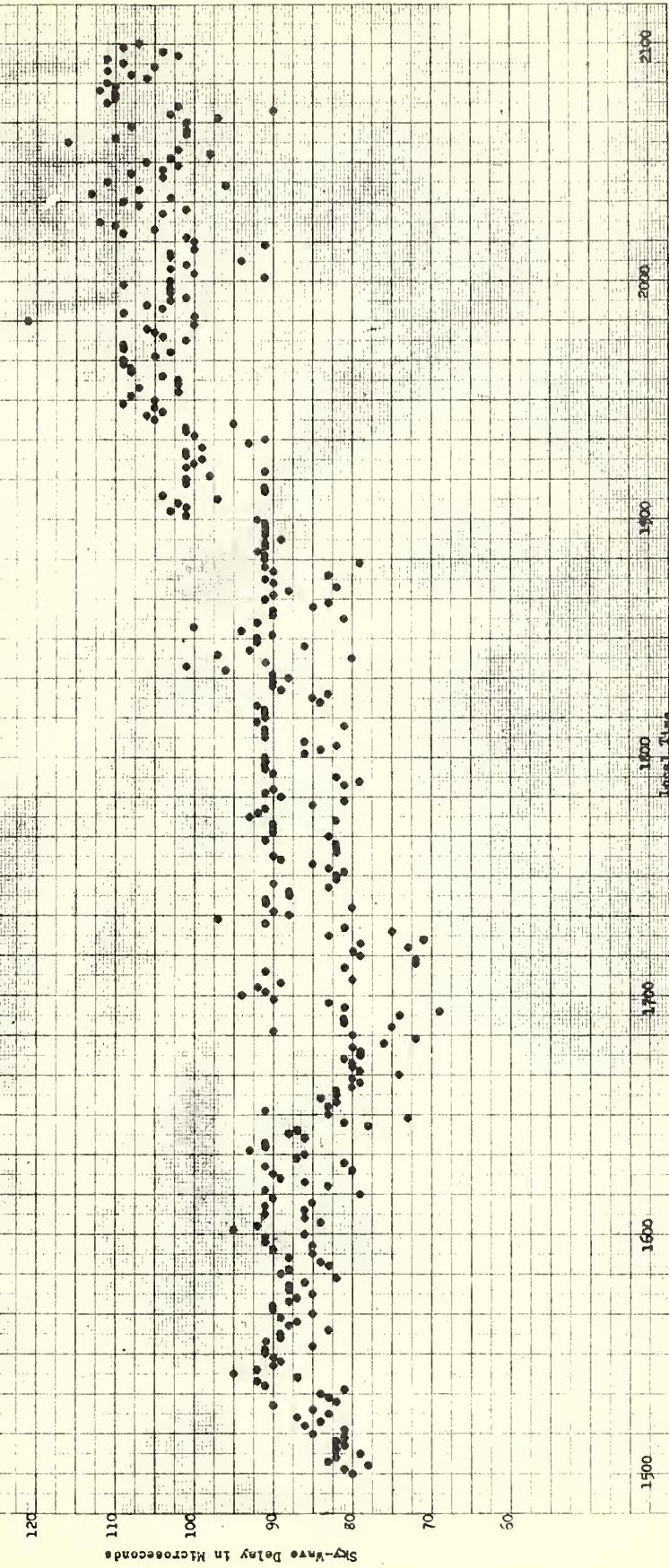


Fig. 13.

12 FEB 1944

ARMED SERVICES RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Step-Wave Delay vs. Time of Day
Sterling, Virginia
2100 to 0300 Local Time
29-30 December 1943
Distance: 689 Kilometers

Distance: 689 Kilometers

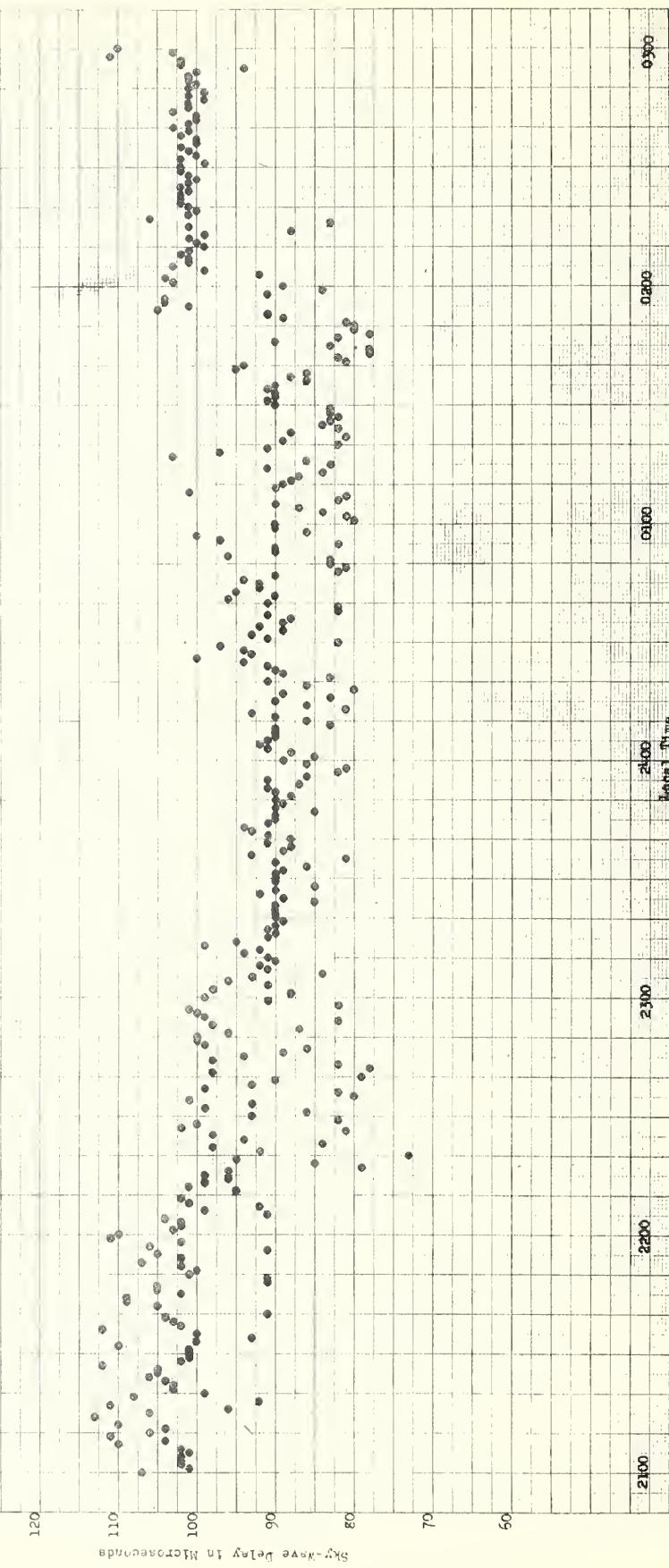


Fig. 14.

12 Feb 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Spec. Wave Delay vs. Time of Day
Starting: 1940 Local Time
0100 to 0900 Local Time
30 December 1943
Distance: 689 Kilometers

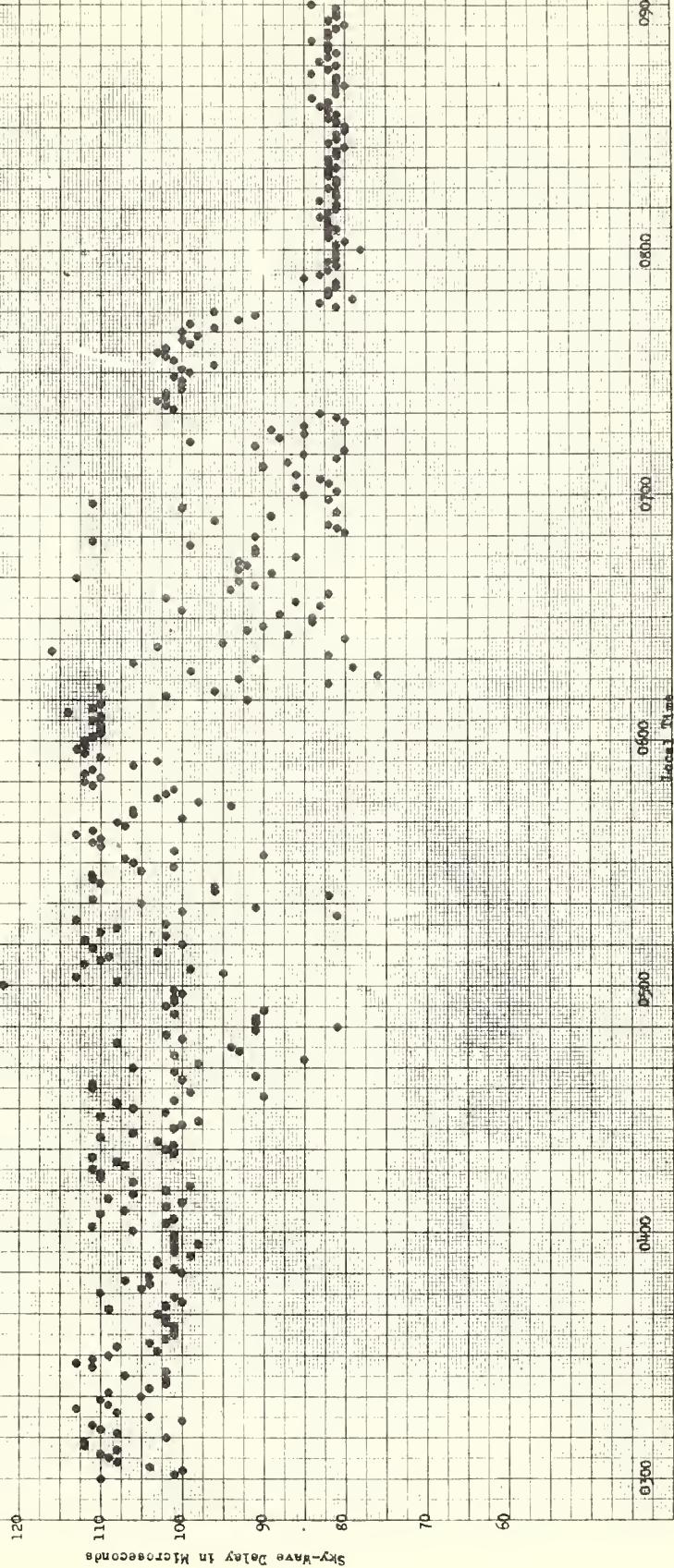


Fig. 15

18 FEB 1964

EXPERIMENTAL HUMMINGBIRD FLIGHTS

FINAL DURATION STATISTICS

Yanagihara, D. S.

See: *Flight vs. Flock or Fly*

Stony Lake, Virginia

0900 to 1500 Second Time

30 Specimens - 40g

Distance: 669 Kilometers

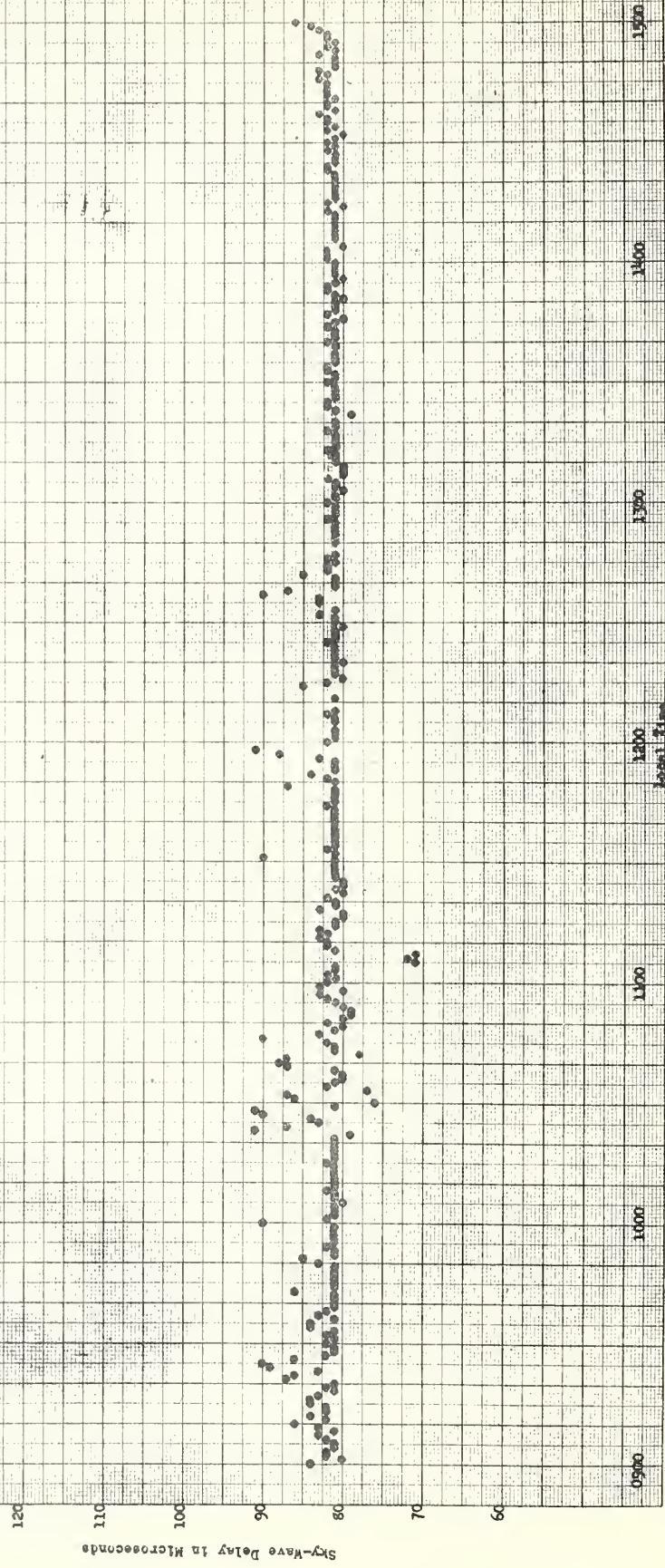
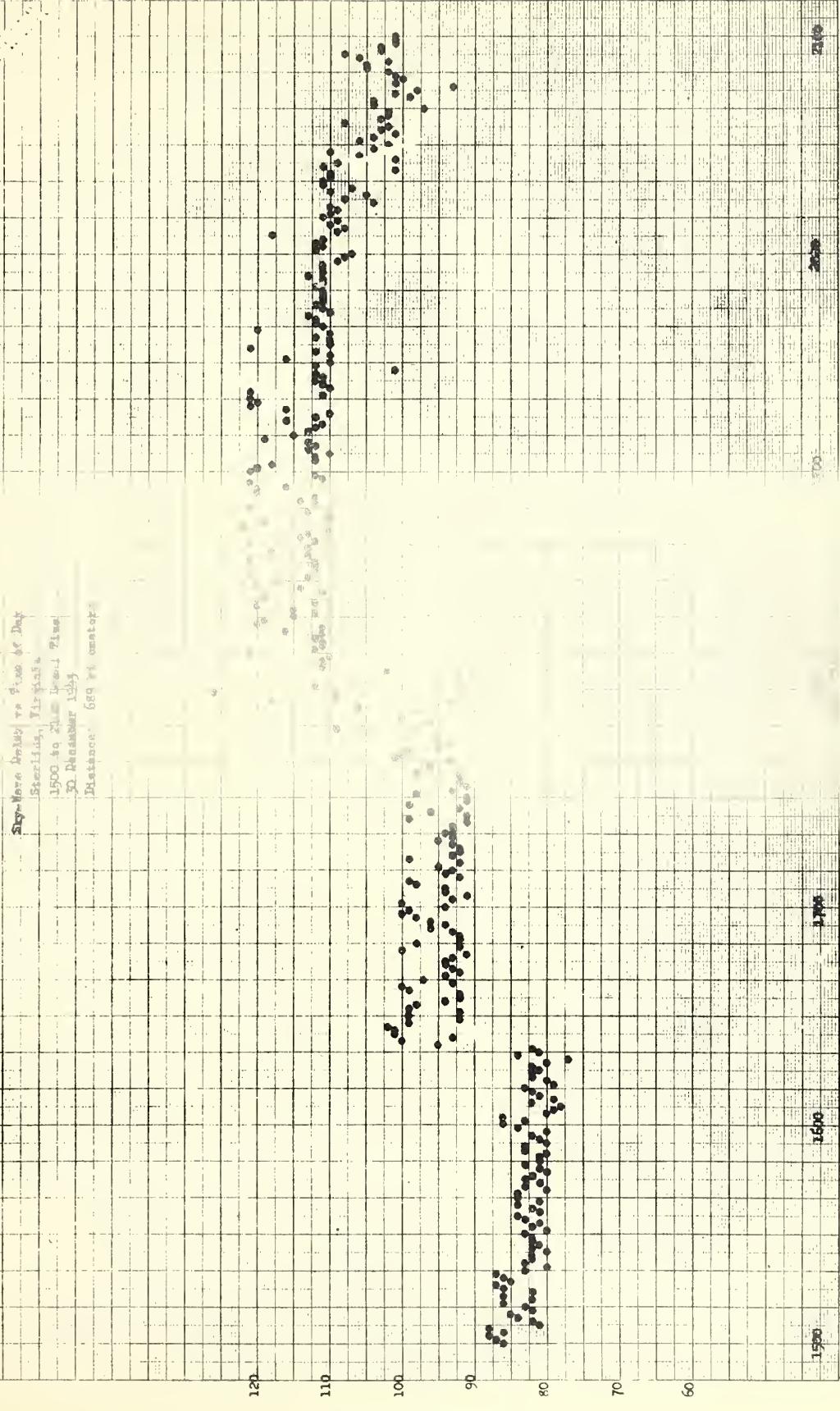


Fig. 16.

WICHITA SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Sky-Mine Delay vs. Distance
Sterling, Virginia
1500 to 2000 hours
D. Deutscher 12/3
Distance: 667 mi. on 500



12 FEB 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Wachlogia D. 25

Simplifying the Time of Day

卷之三

Digitized by Local Line

18 Jeannery 19th
Distance: 442 kilometers

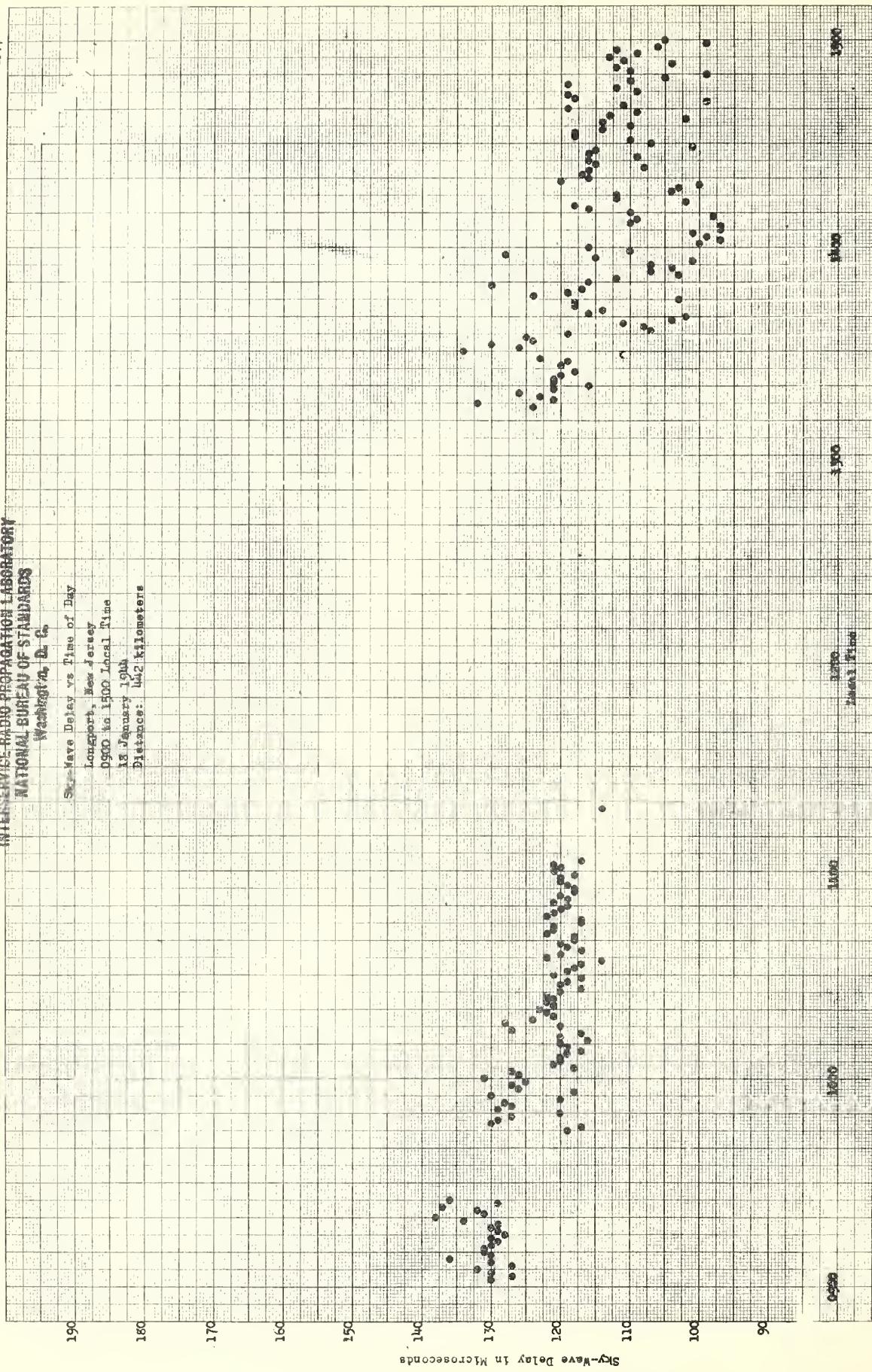


Fig. 18.

12 FEB 1944

INTERFERENCE RADIO PROPAGATION INVESTIGATION

NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Sky-Wave Delay vs. Time of Day

Londonderry, New Jersey

1500 to 2100 hours, EST

18 January 1944

Distance: 442 miles

137

130

127

120

115

110

105

100

95

90

1500

1600

1700

1800

1900

2000

2100

Sky-Wave Delay in Microseconds

Fig. 19.

INTERSERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Short-Wave Delay vs Time of Day
Longport, New Jersey
2100 to 0100 Local Time
18-19 January 1941
Distance: 112 kilometers

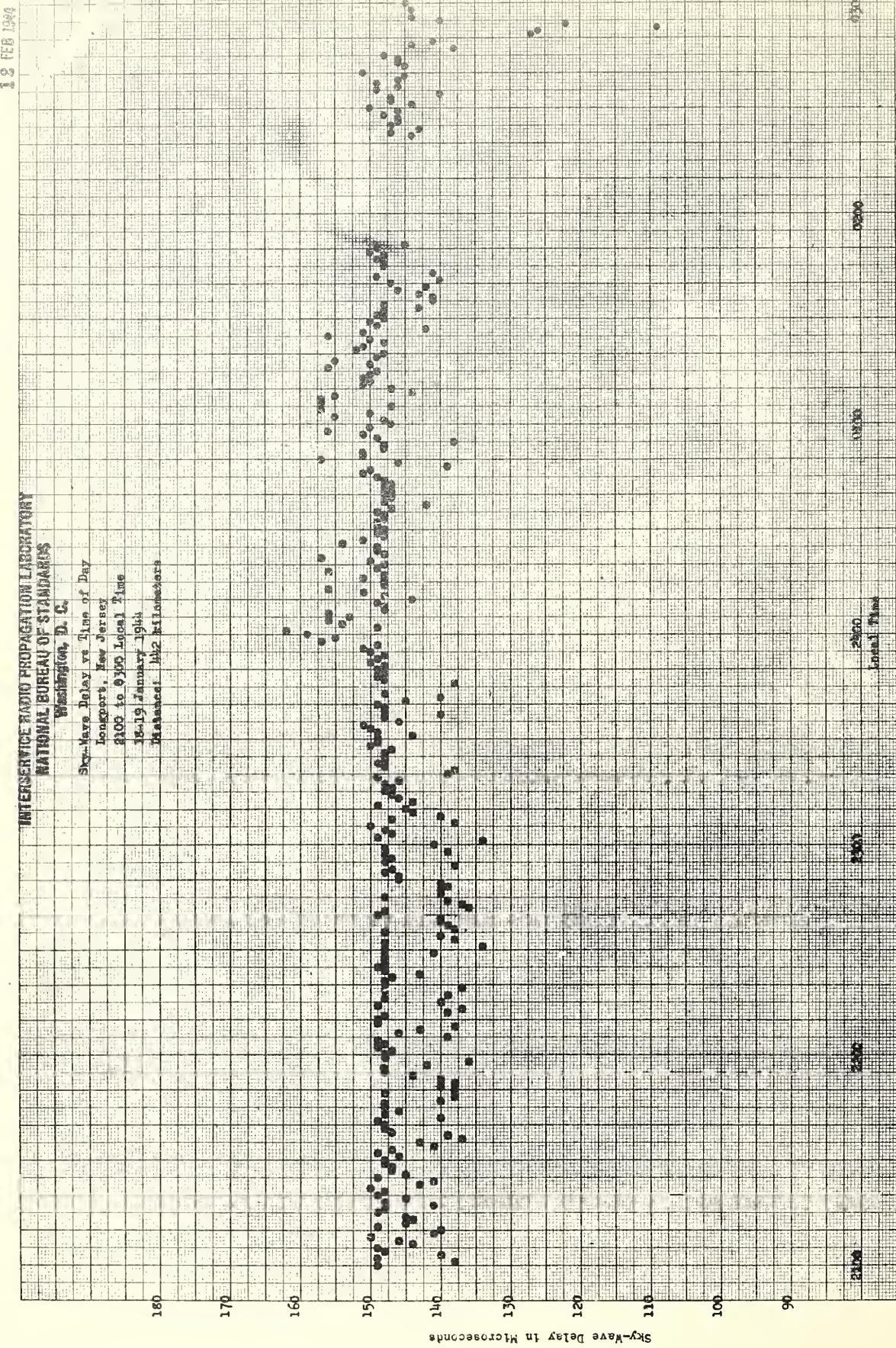


Fig. 20.

12 Feb 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Station Delay to Time of Day
Leicester, New Jersey

0300 to 0900 Local Time
19 January 1944
Distance: 332 miles east

190

170

160

150

140

130

120

110

100

90

0300

0400

0500

0700

0900

0900

SKY-WAVE DELAY IN MICROSECONDS

Fig. 21.

INTERSERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Stop: Mata July or Time of Day
Langport, New Jersey
0900 to 1500 Local time
19 January 1944
Distance: 885 kilometers

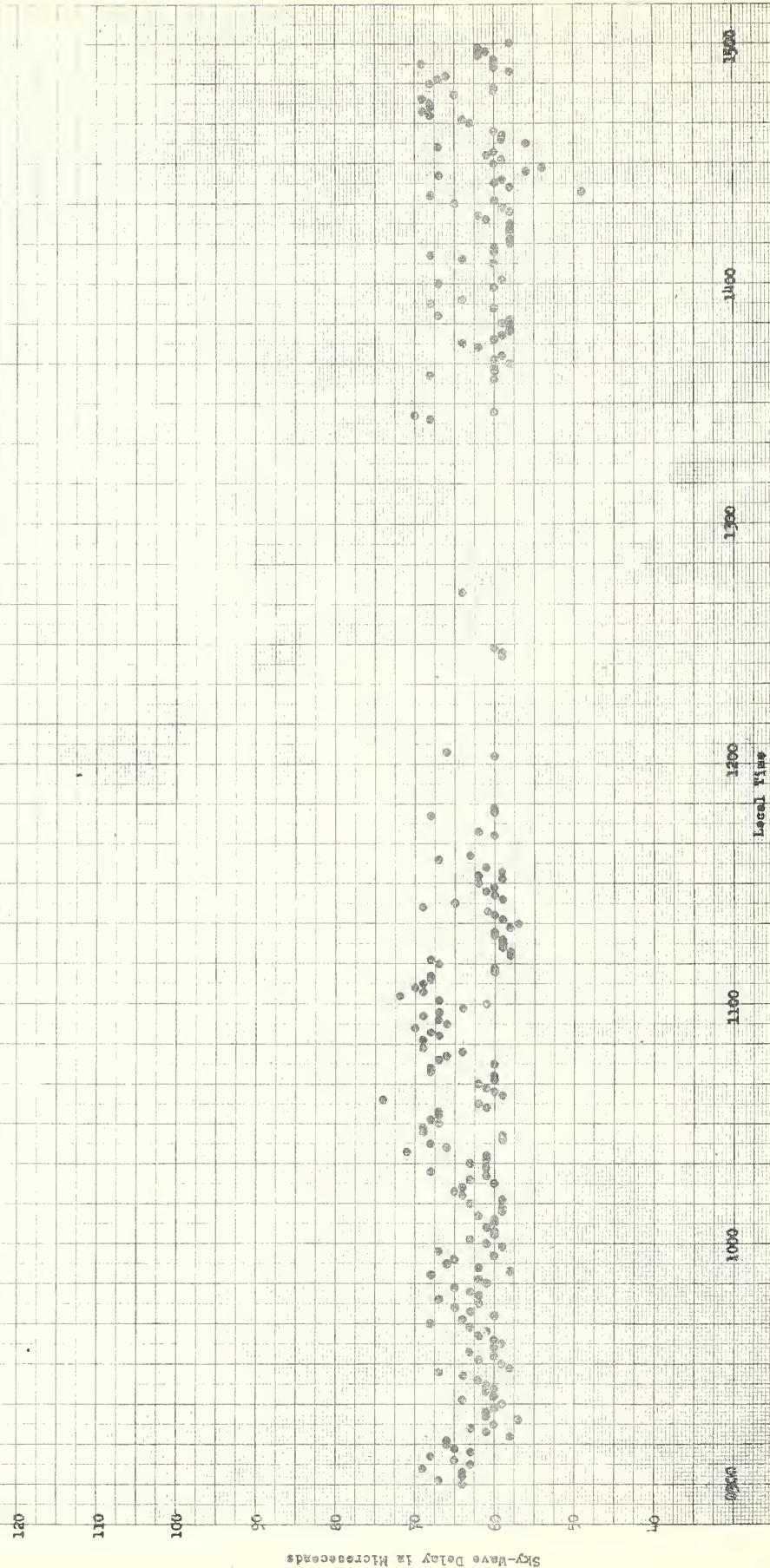


Fig. 22.

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Ground Wave Delay vs. Time of Day
Latitude: 35° 52' Lat.
1500 to 2100 Local Time
19 January 1948
Distance: 685 kilometers

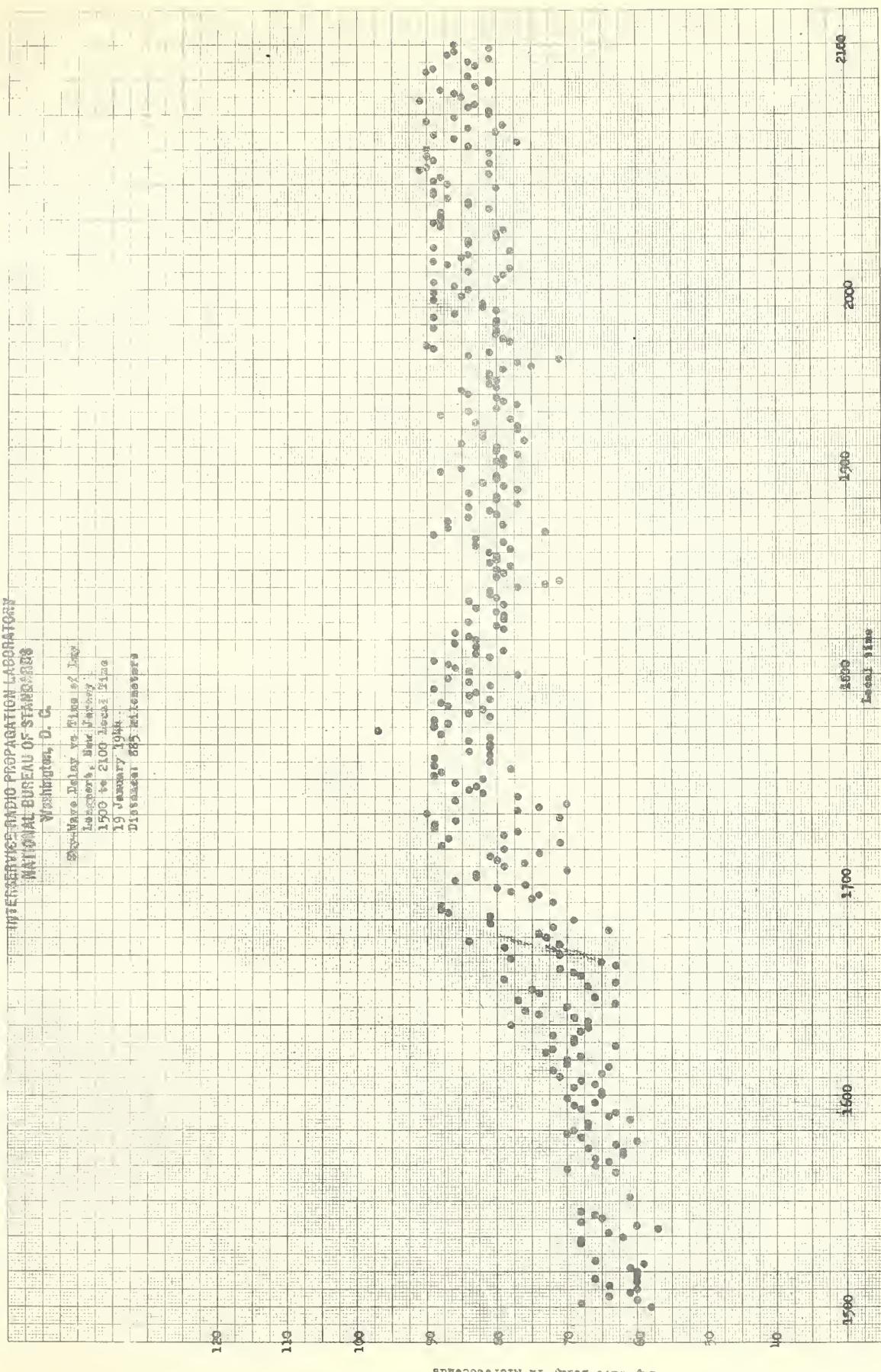


Fig. 23.

12 FEB 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Sky-Wave Delay versus Day
Lengis et. New Jersey
1200 to 0100 Local Time
19-20 January 1944
distance 685 kilometers

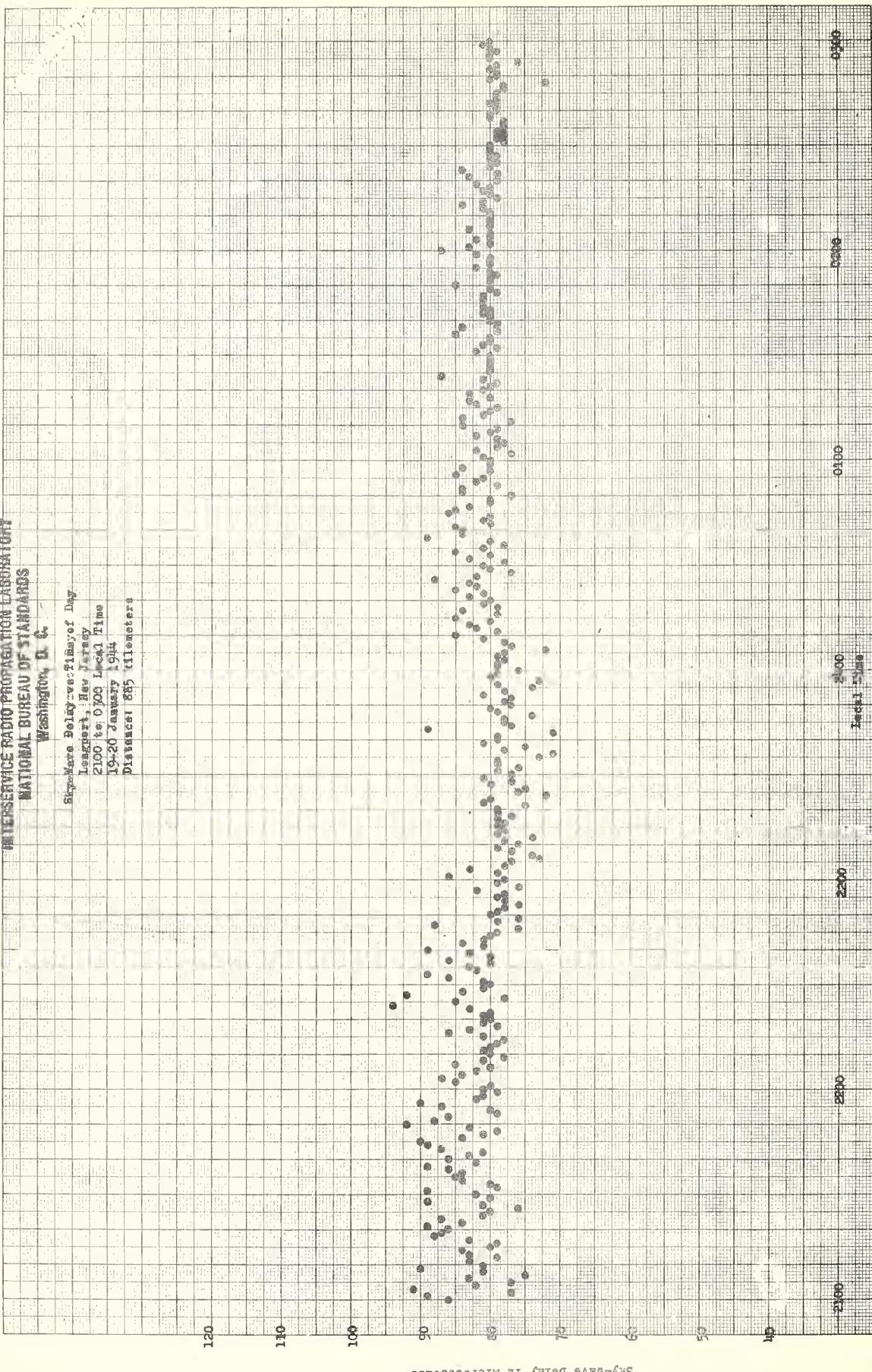


Fig. 24.

12 FEB 1944

INTER-SERVICE RADIO PREPARATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Sgt. Major, Detach. 2, 5th Ordnance
Transport, New Jersey

0300 to 0900, 1 April, 1944

SO Agency: 3188
Distance: 305 Kilometers

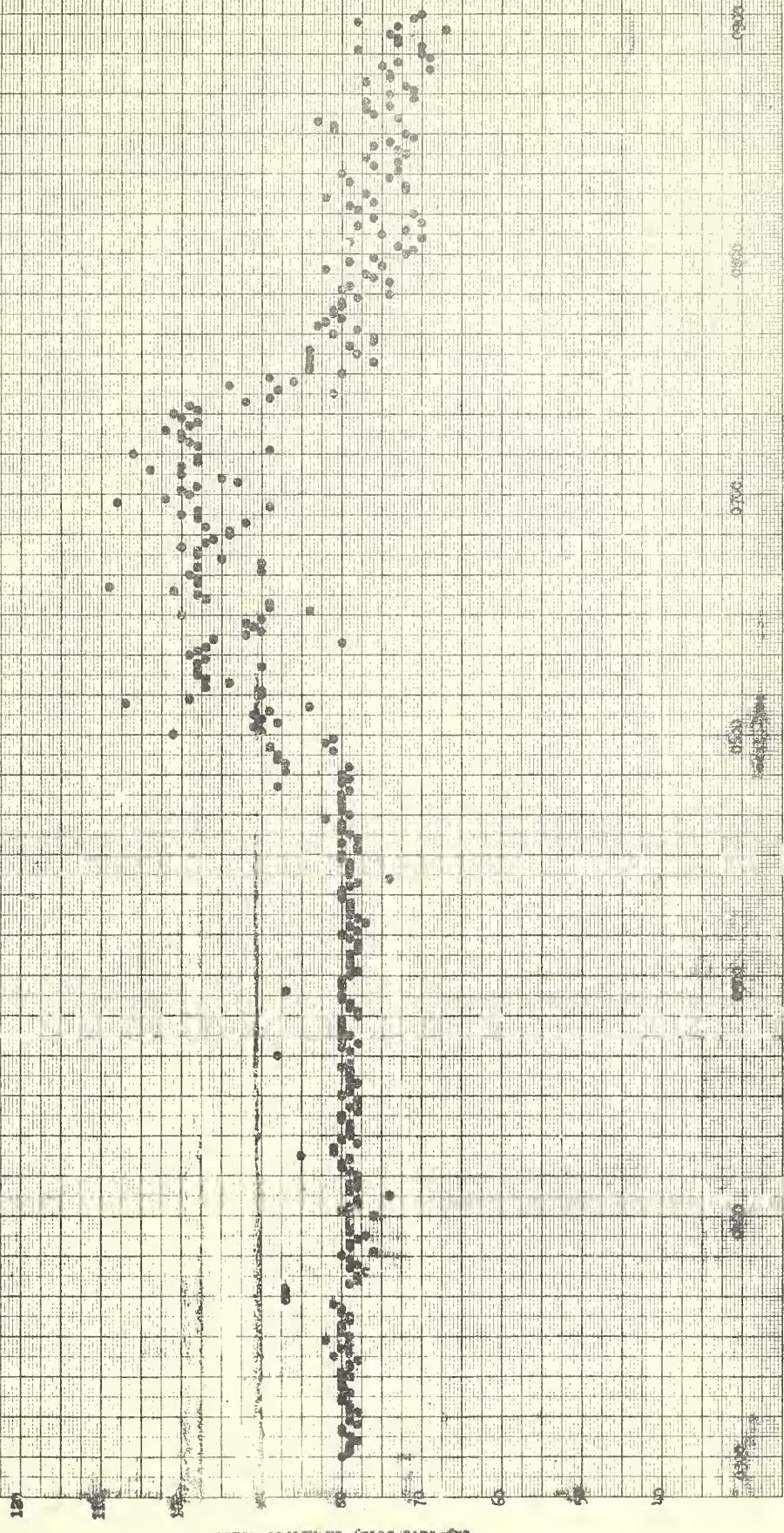


Fig. 25.

12 FEB 1944

UNIVERSITY RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Sky-Wave Delay vs. Time of Day
Langhorne, New Jersey
0900 and 1200 Local Time
20 January 1944
Distance: 102 Kilometers

190

180

170

160

150

140

130

120

110

100

90

80

70

Sky-Wave Delay in Microseconds

1300

1200

1100

1000

900

800

700

Fig. 26.

12 FEB 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Short-Wave Delay vs. Time of Day

Longport, New Jersey

1500 to 2100 Local Time

20 January 1944

Distance: 442 Kilometers

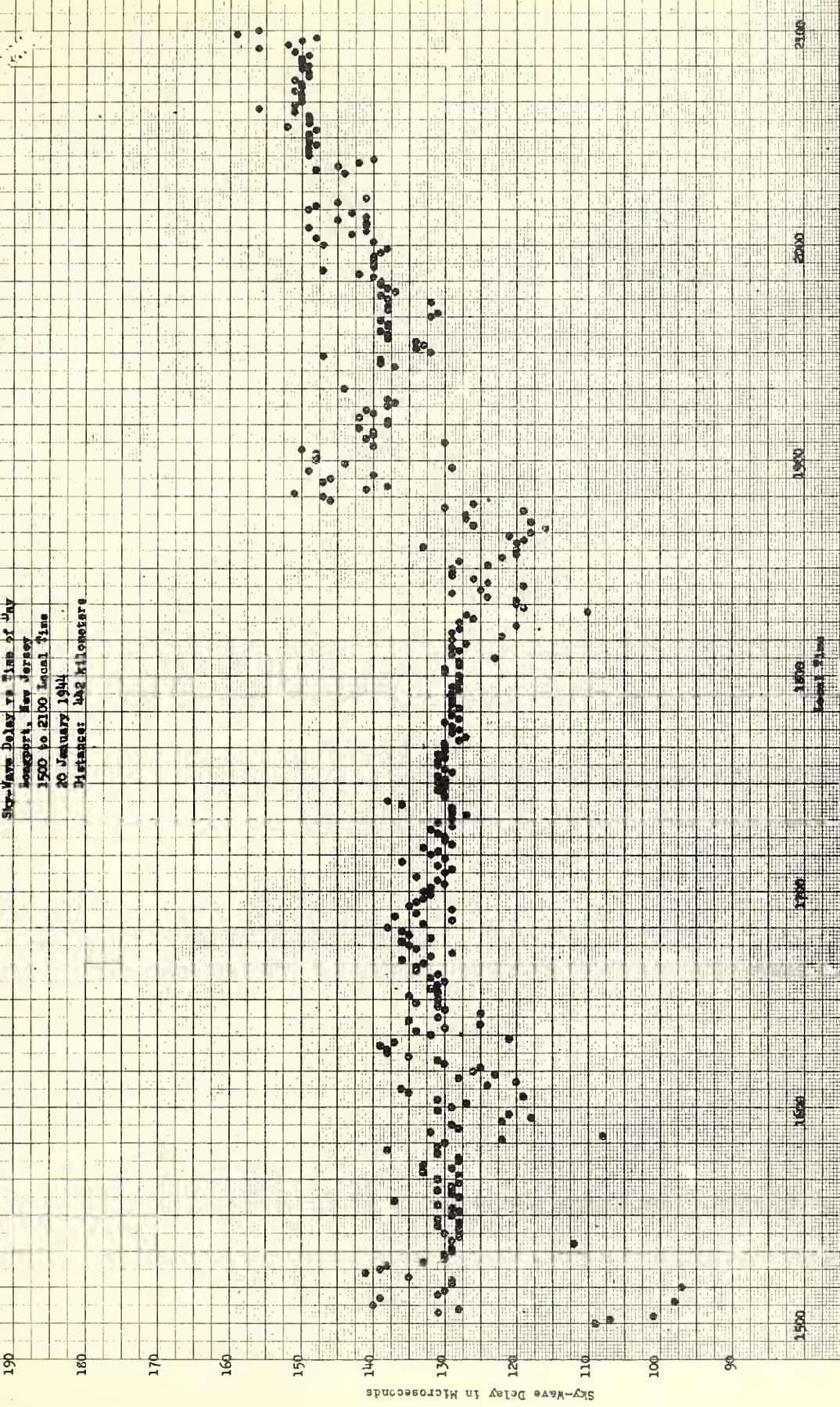


Fig. 27.

12 FEB 1943

WATERSERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Short-Wave Delay vs Time of Day
Longport, New Jersey
0300 to 0900 Local Time
21 February 1943
Distance: 142 Kilometers

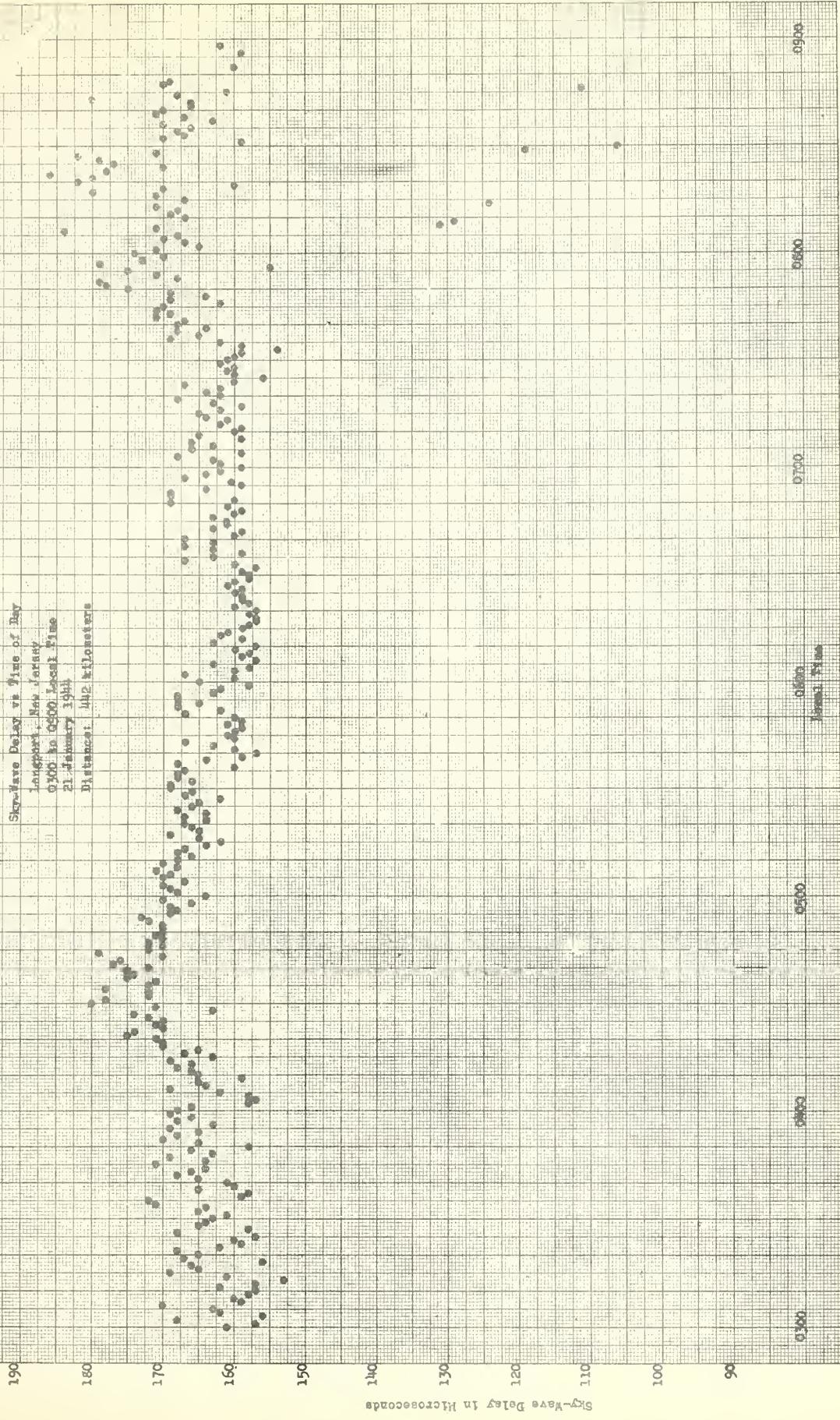


Fig. 29.

12 Jan 1946

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Sky-Wave Delay vs Time of Day

Loneport, New Jersey

0900 to 1900 Local Time

21 January 1946

Distanse: 385 Kilometers

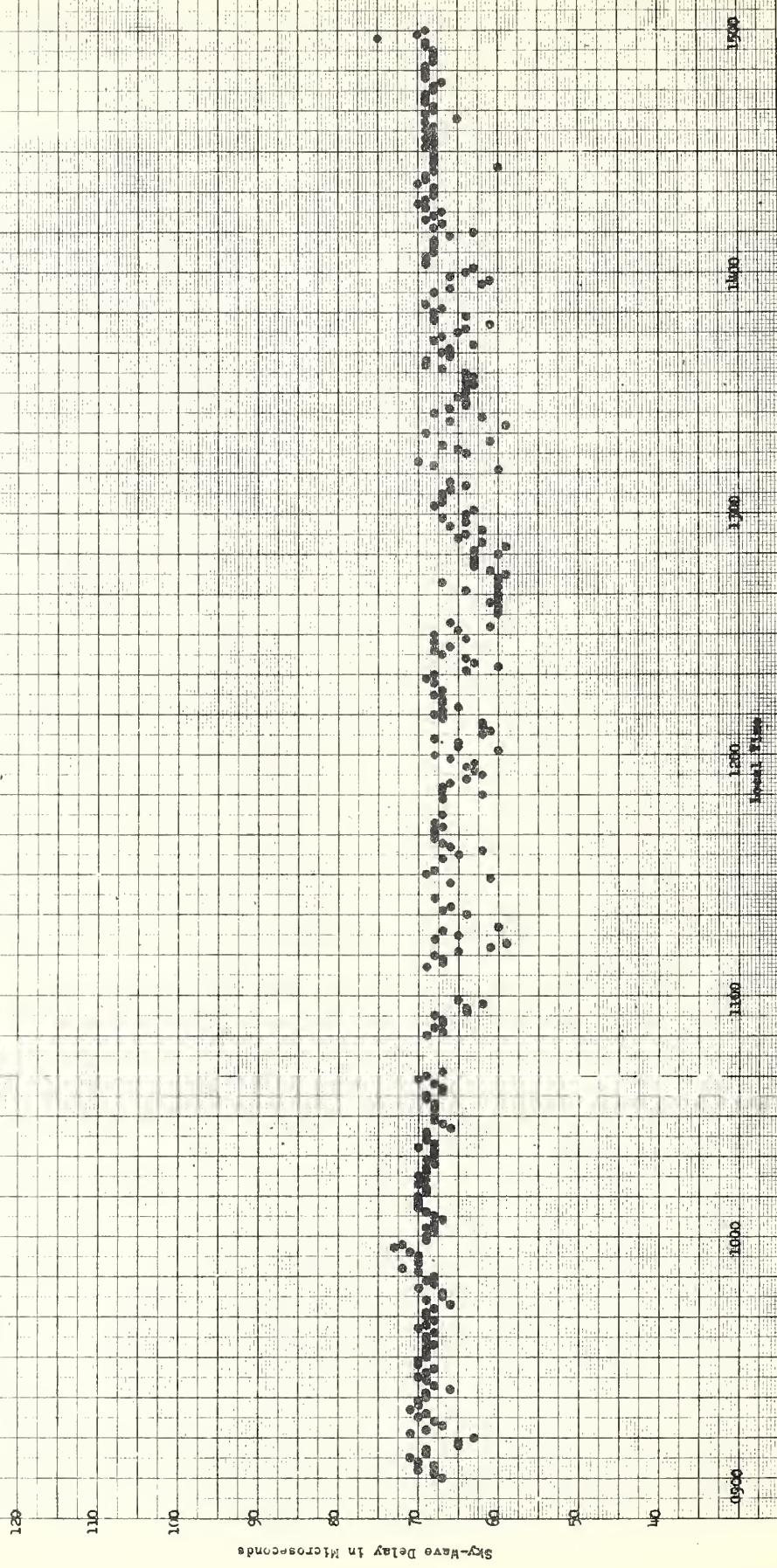


Fig. 30.

INTER-SERVICE RADIO PROPAGATION LABORATORY

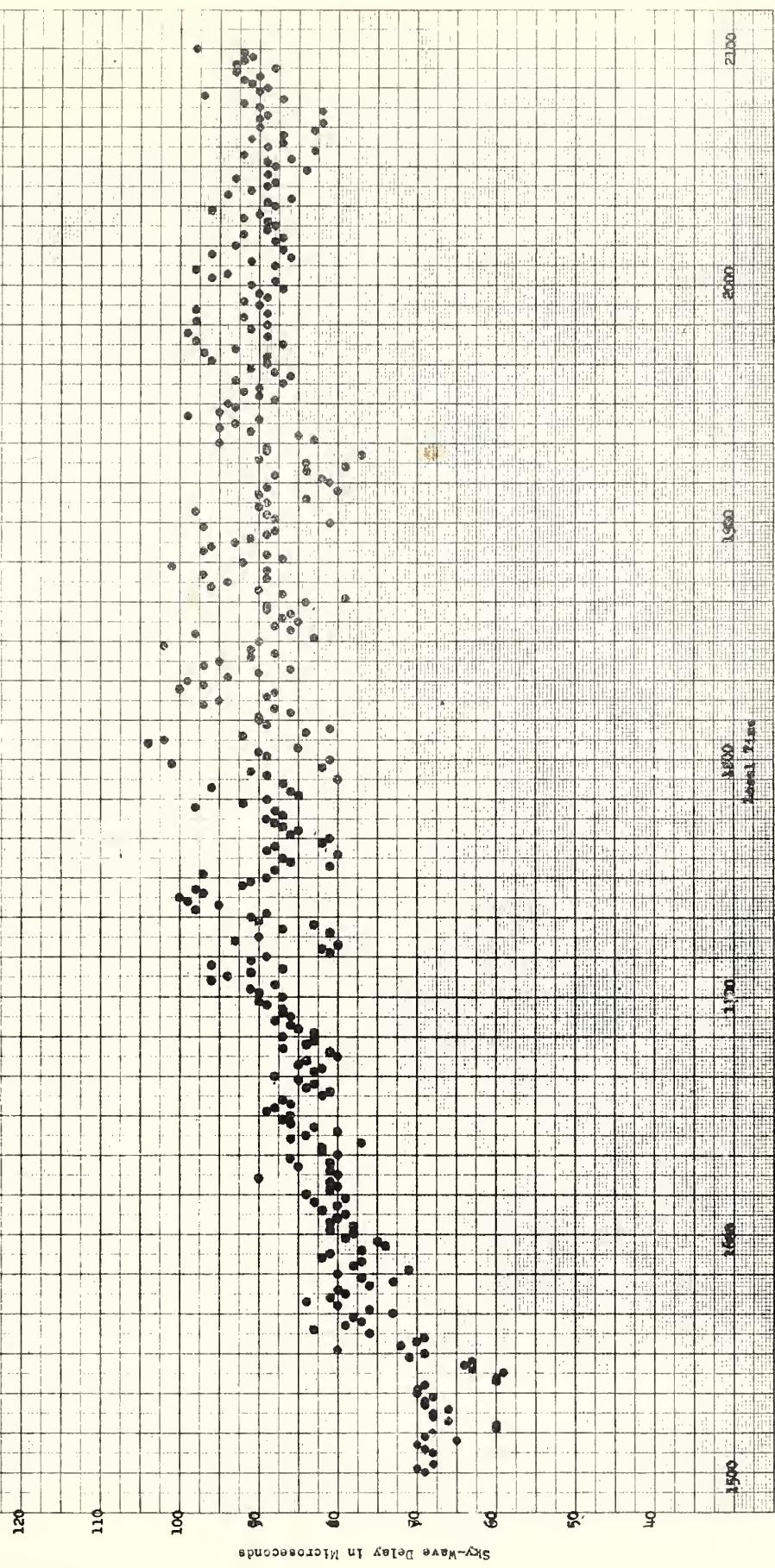
NATIONAL BUREAU OF STANDARDS
Washington, D. C.Sky-Wave Delay vs Time of Day
Longport, New Jersey
1500 to 2100 Local Time
21 January 1944
Distance: 365 Kilometers

Fig. 31.

12 Feb 14

INTERFACIAL RAY PROPAGATION LAYER

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

SKY-WAVE DELAY vs TIME OF DAY

Longshore, New Jersey

2100 to 0300 Local Time

21-22 January 1964

Distance: 555 Kilometers

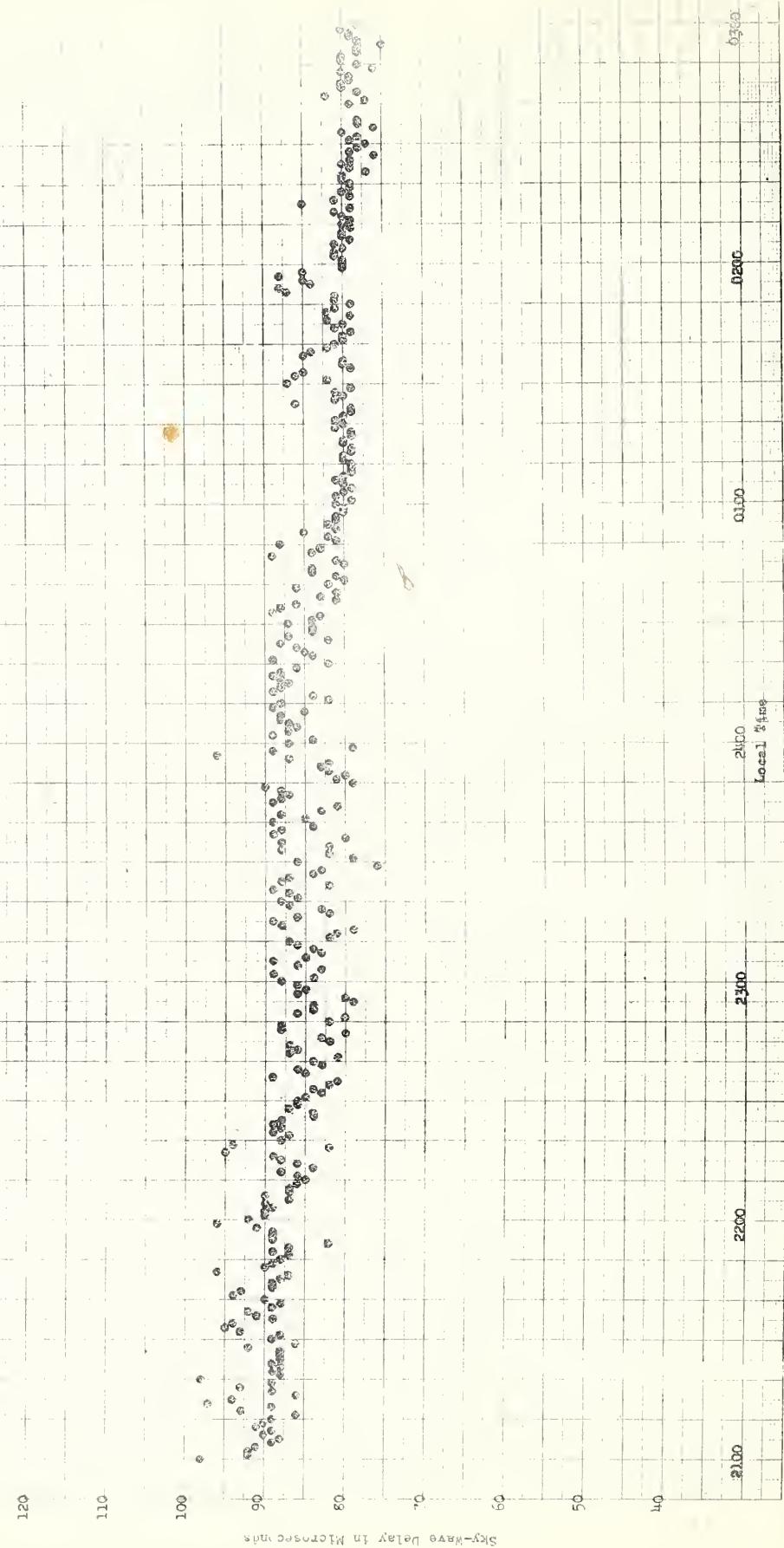


Fig. 32.

12 FEB 1944

TELE-SERVICE HAVING PROPRIETARY INFORMATION

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

State-Power Delay vs Time of Day
London, New Jersey
0000 to 0900 Local Time
22 January 1944
Distance 1855 miles

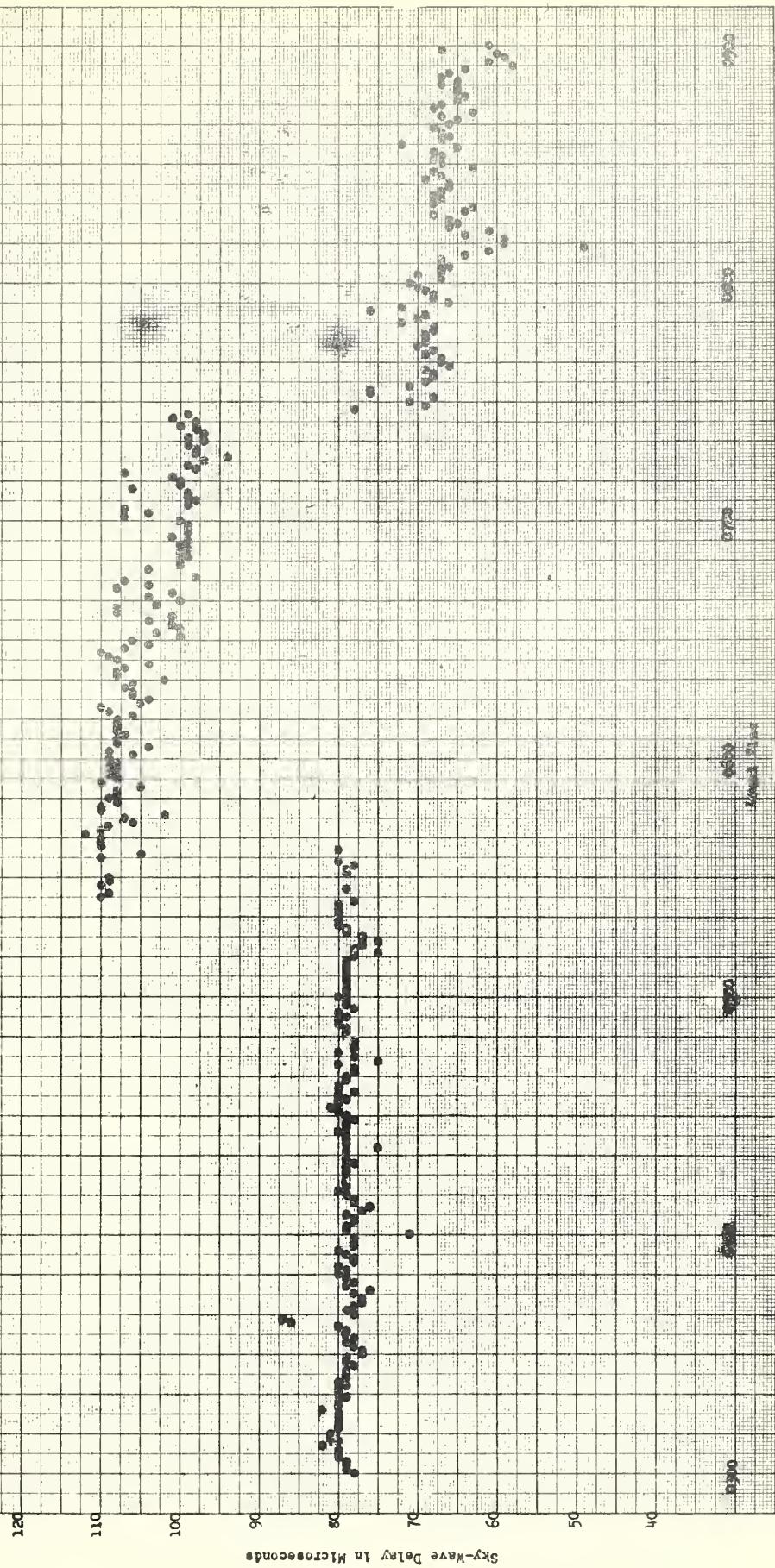


Fig. 33.

INTERSERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Distribution of Sky Wave Observations

28-30 December 1947

Frequency: 1.850 kHz voxels

Distance: 658 kilometers

0900 to 1500 Local Time

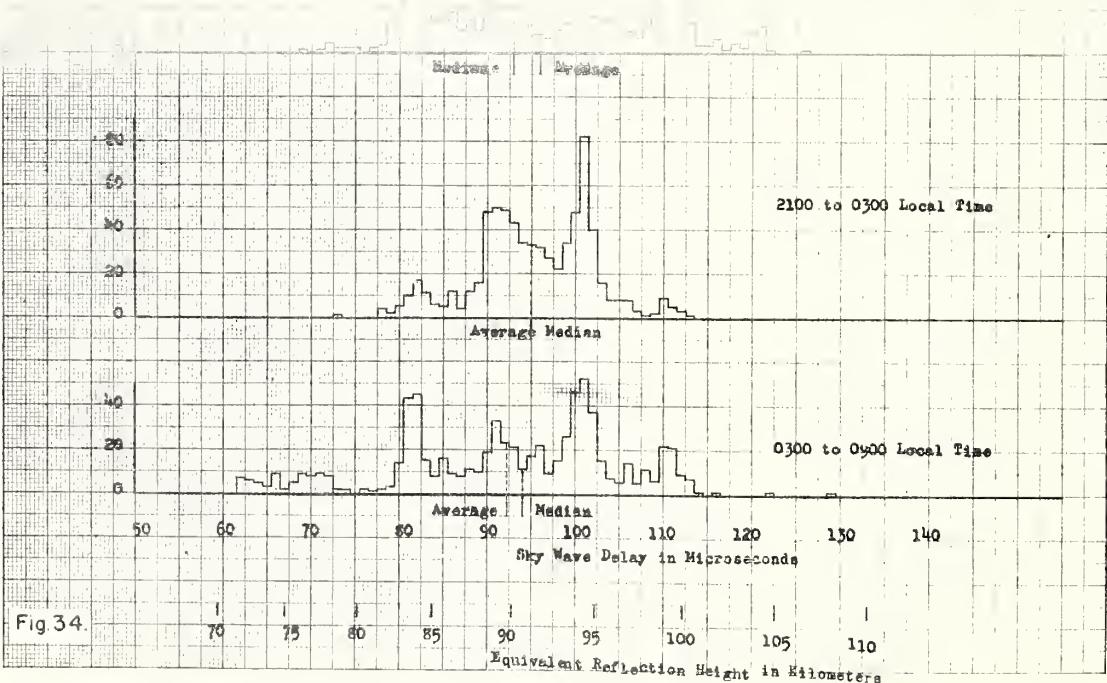
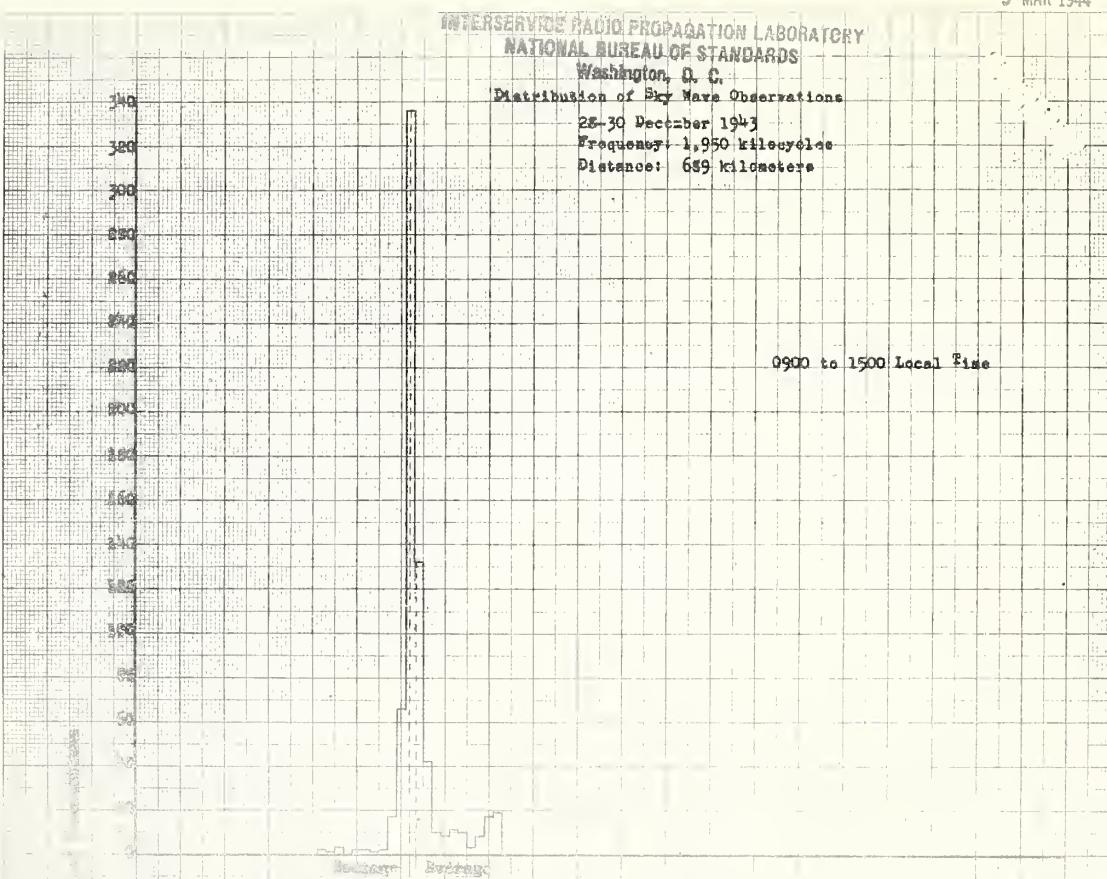


Fig. 34.

INTERSERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

9 MAR 1944

Washington, D. C.

Distribution of Sky Wave Delay Observations

1943 January 18th

Frequency: 1,000 kilocycles

Distance: 1,000 miles

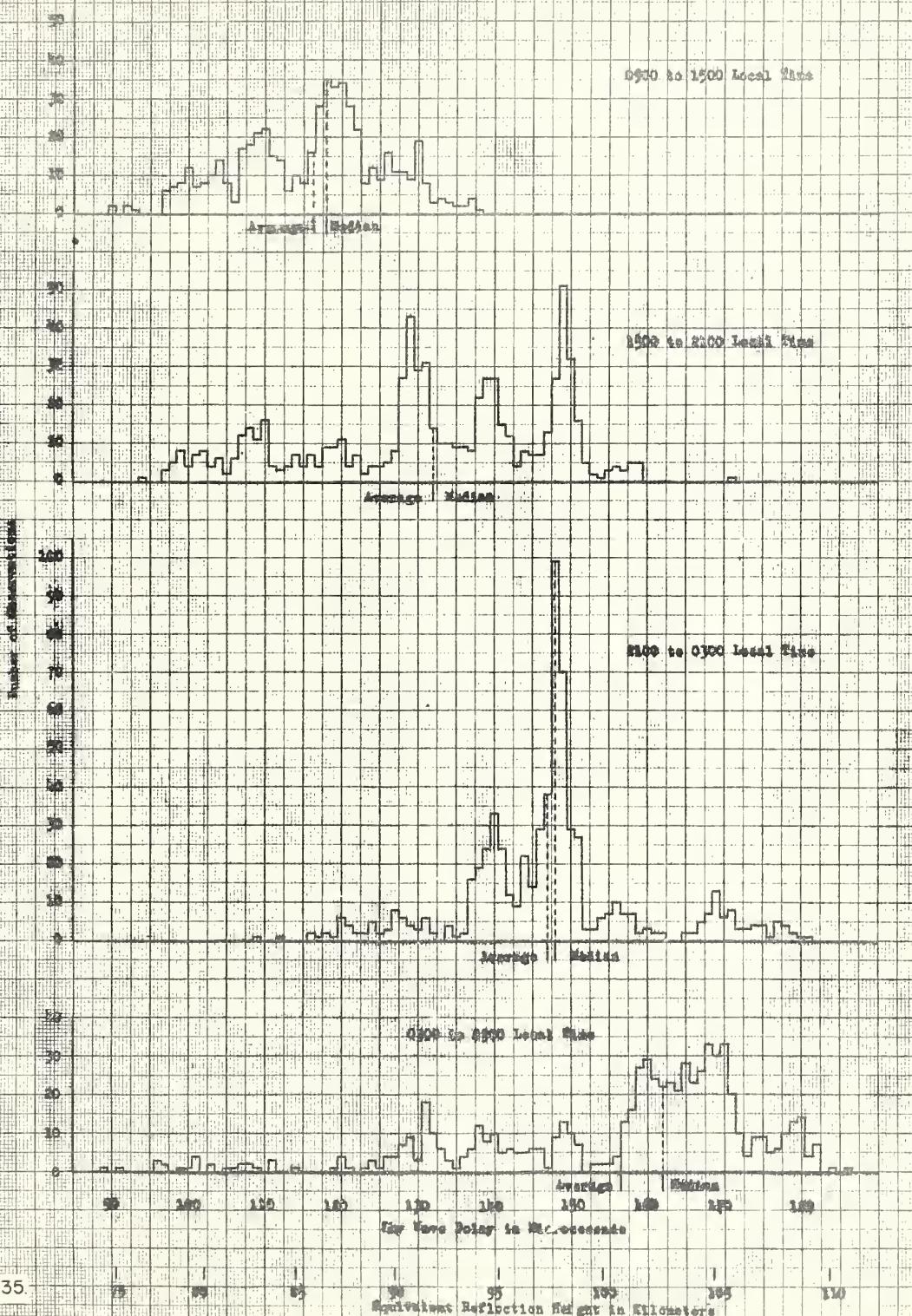


Fig. 35.

8 MAR 1944

INTERSERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Distribution of Sky Wave Observations

19-22 January 1944

Frequency: 1,950 kilohertz

Distance: 835 kilometers

0900 to 1500 Local Time

Average Median

1500 to 2100 Local Time

Average Median

0300 to 0900 Local Time

Average 85 100 110 120
Sky Wave Delay in Microseconds

Equivalent Reflection Height in Kilometers

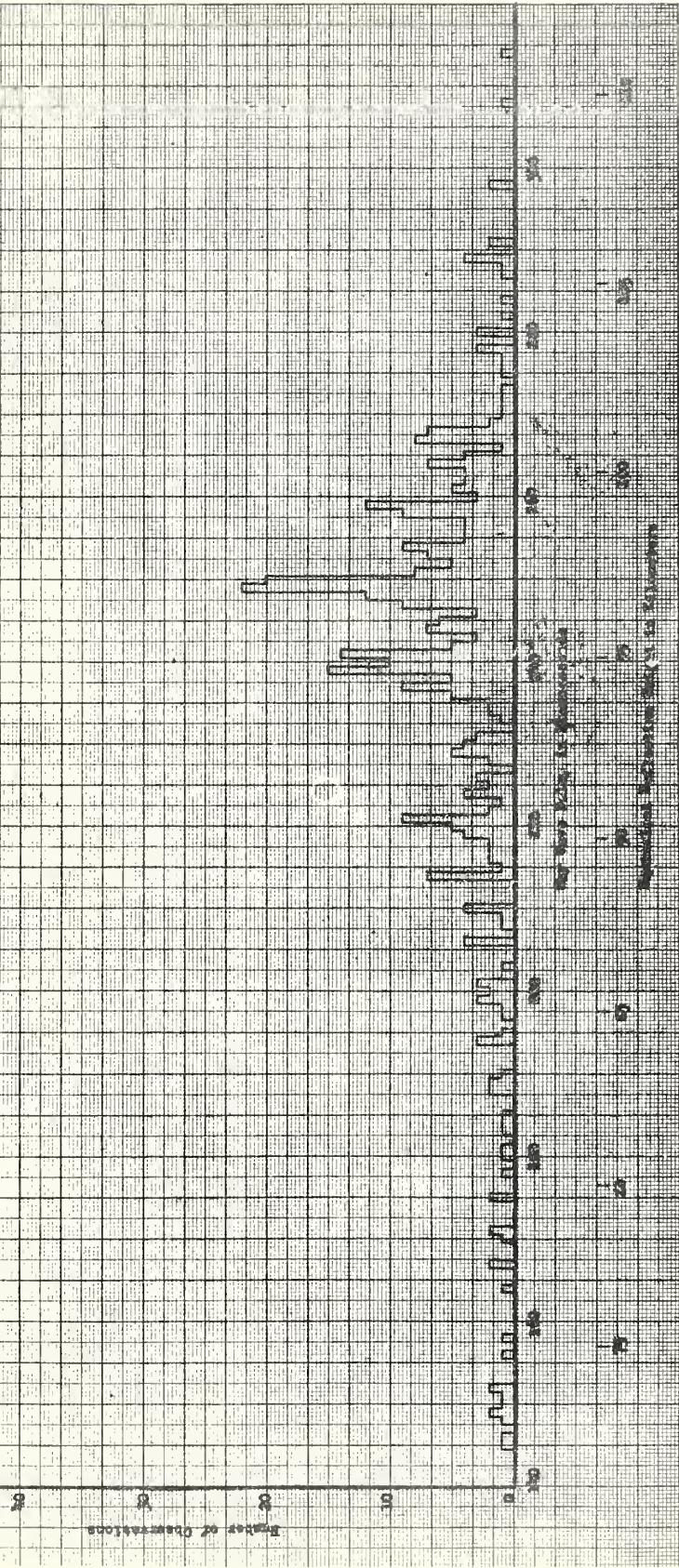
Fig 36

9 MAR 1944

INTERFERENCE RADAR PROPAGATION LAYER DATA

Washington, D. C.

Map 1. Frequency distribution of sky wave decay characteristics
Washington, D. C. to 100 kilometers
Frequency 1000 to 10000 megahertz
Number of observations 1000



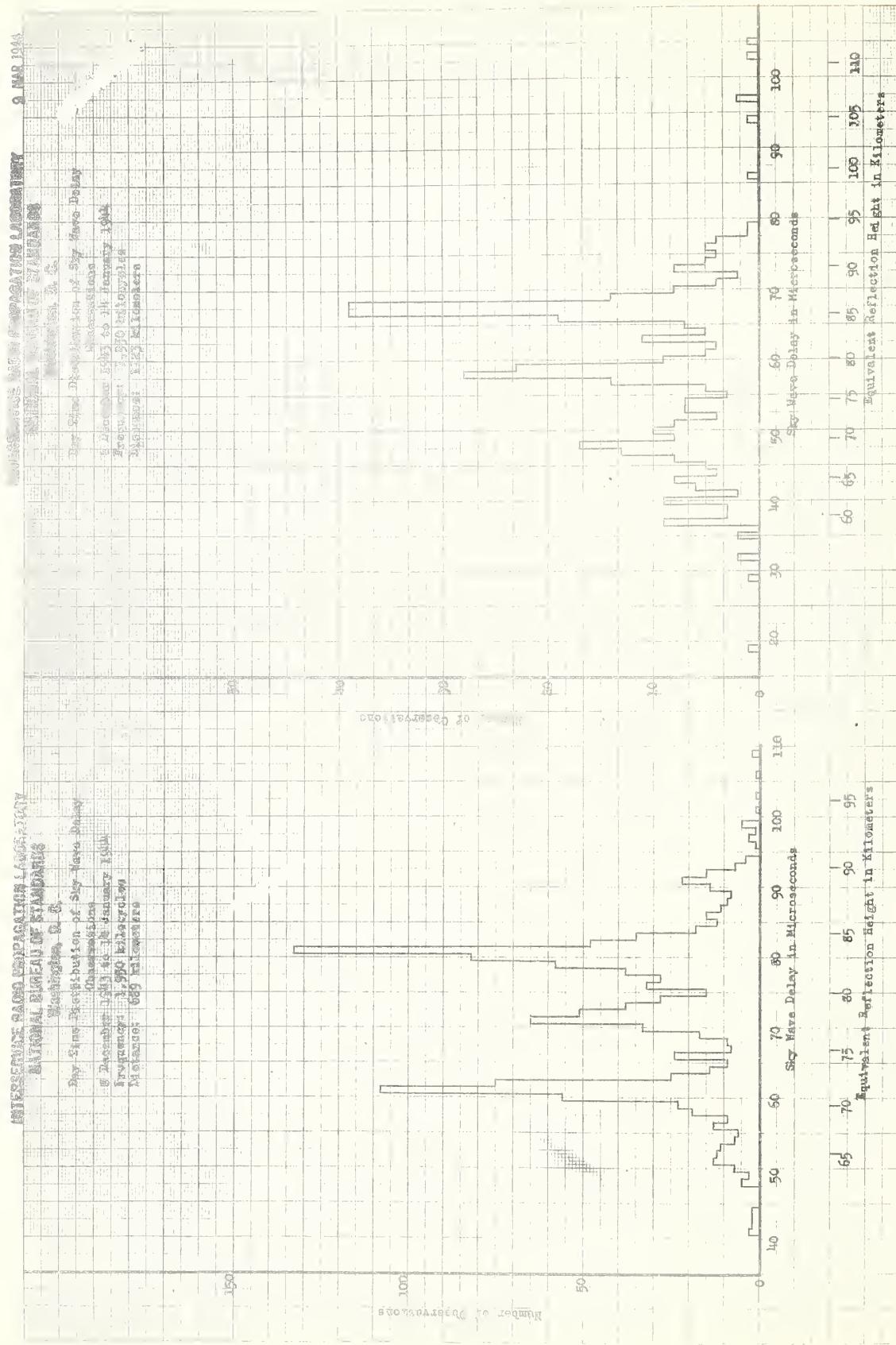


Fig. 38.

8 MAR 1944

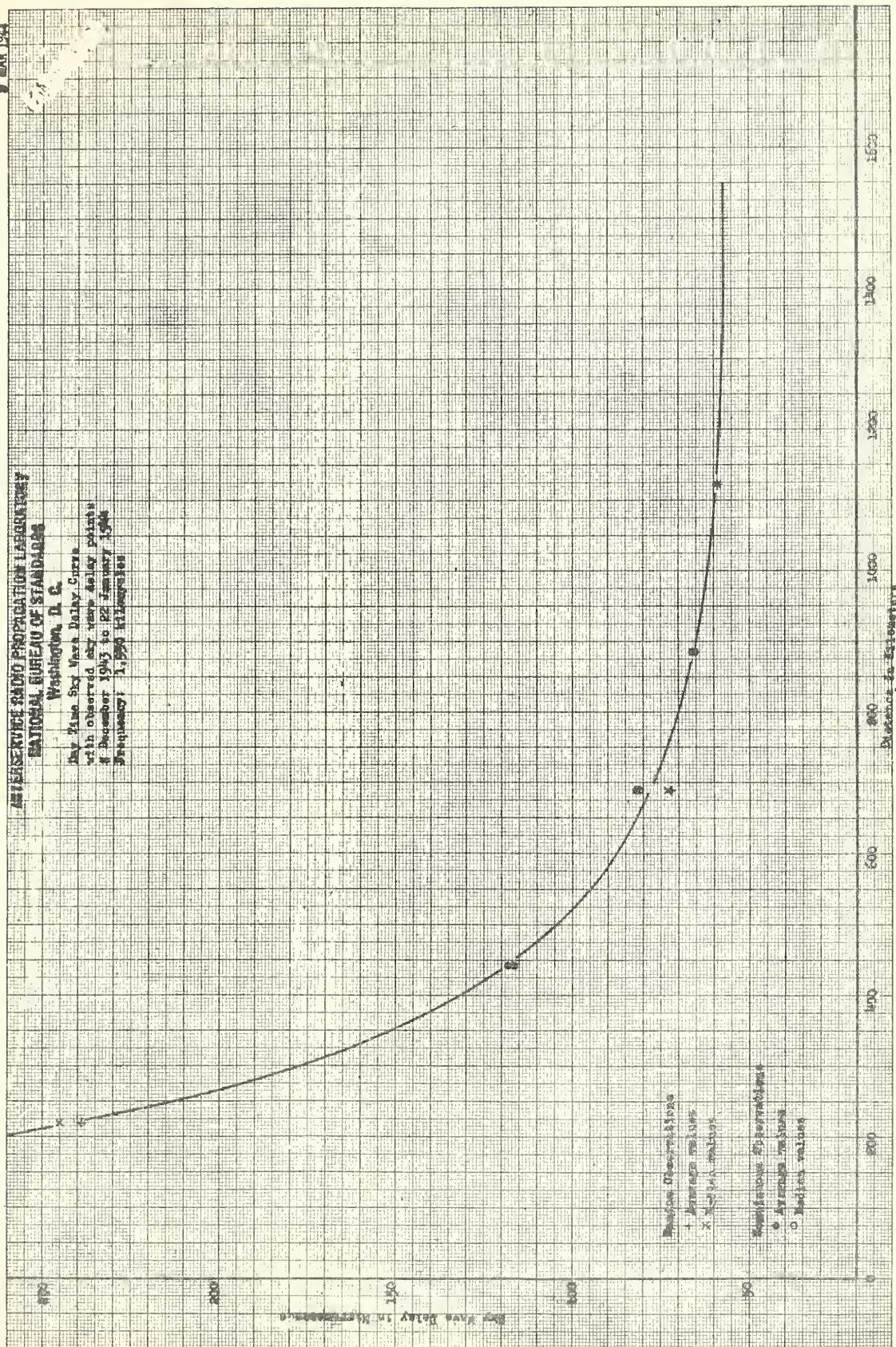
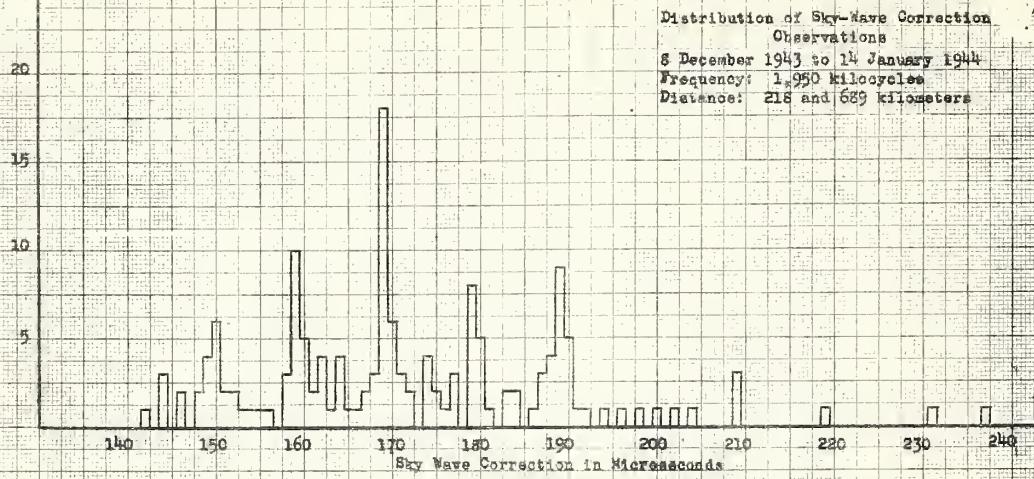


Fig. 39.

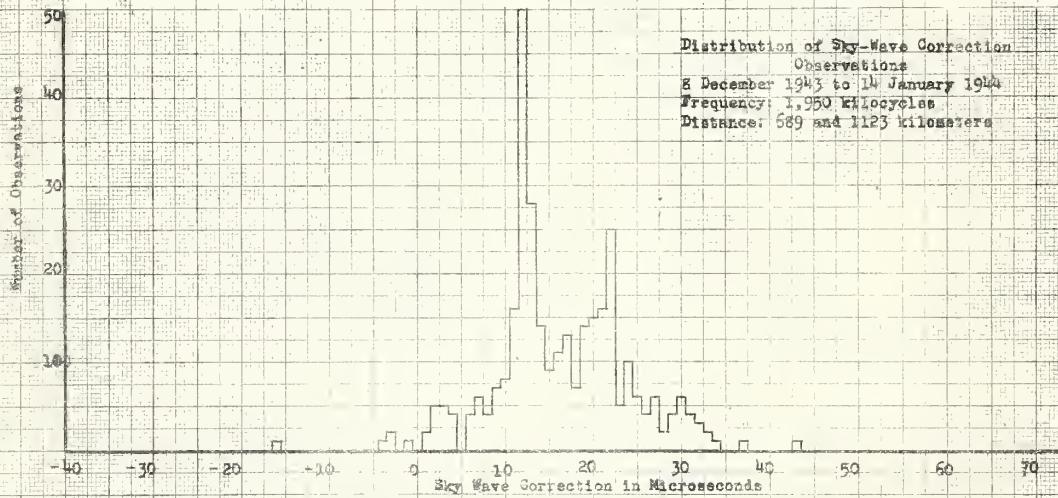
8 MAR 1944

INTERSERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Distribution of Sky-Wave Correction
Observations
8 December 1943 to 14 January 1944
Frequency: 1,950 kilocycles
Distance: 218 and 689 kilometers



Distribution of Sky-Wave Correction
Observations
8 December 1943 to 14 January 1944
Frequency: 1,950 kilocycles
Distance: 689 and 1123 kilometers



Distribution of Sky-Wave Correction
Observations
8 December 1943 to 14 January 1944
Frequency: 1,950 kilocycles
Distance: 1123 and 1514 kilometers

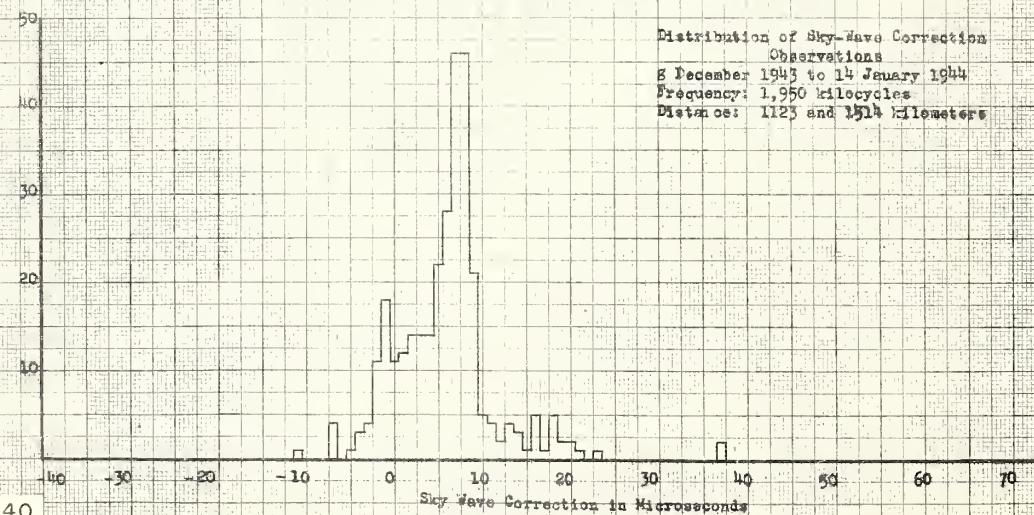


Fig. 40.

9 MAR 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Ray Film Sky Wave Delay Surveyor's Notes
With Shaded sky wave corrected points
December 1943 to 11 January 1944

Frequency 1,990 kilocycles

Distances 316 and 689 kilometers

1,123 and 1,127 kilometers

1,123 and 1,511 kilometers

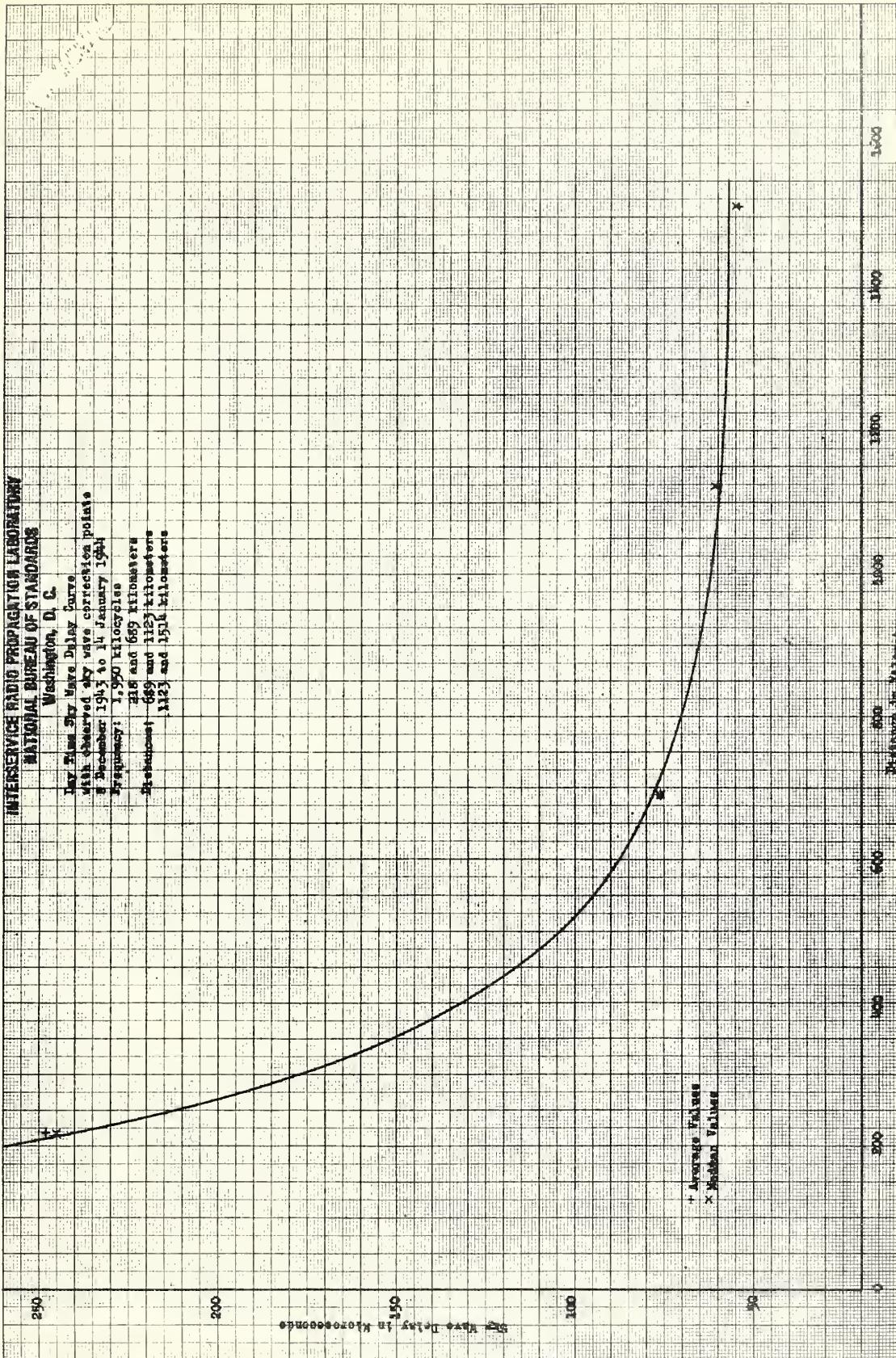


Fig 4.

9

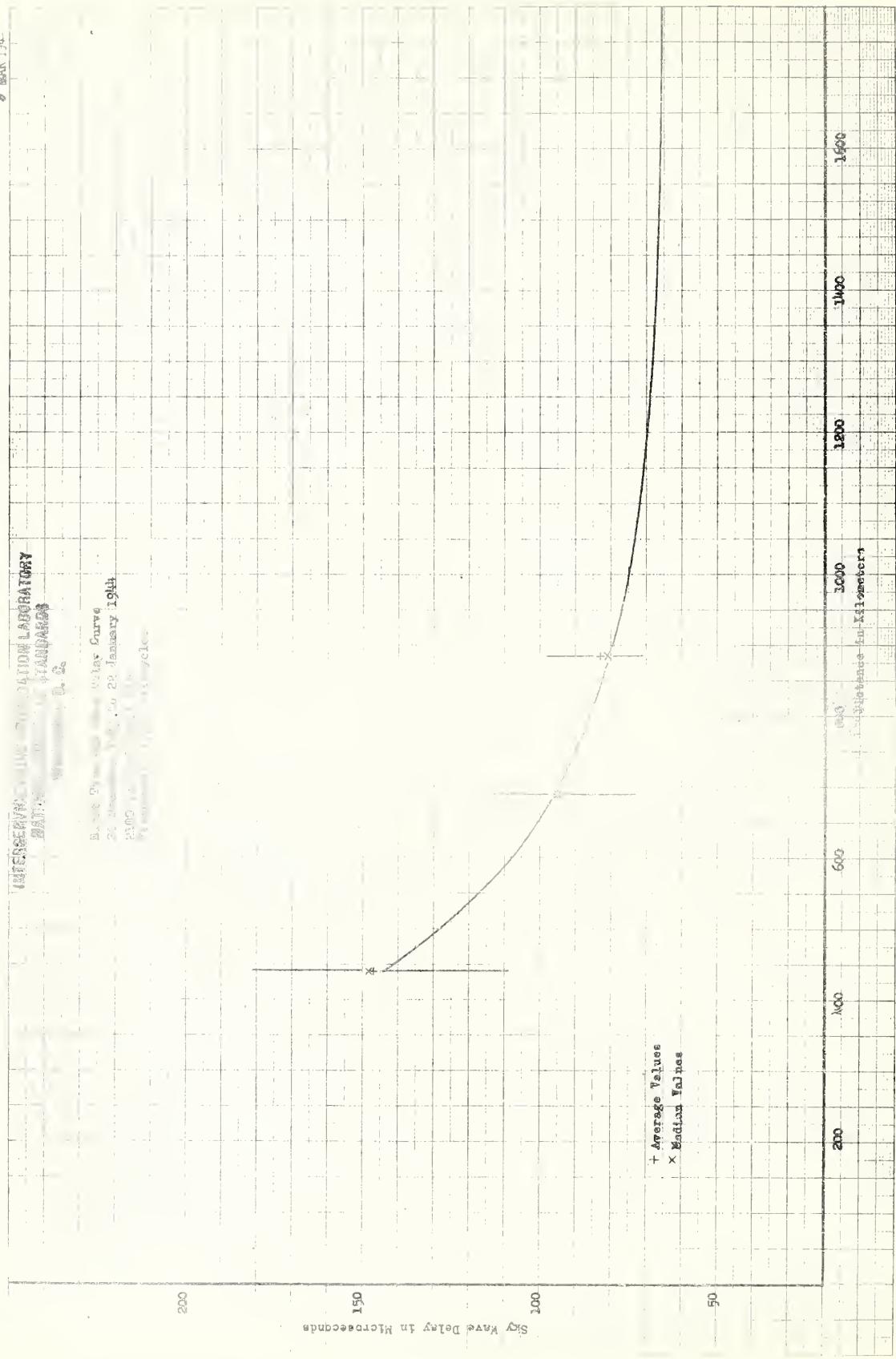


Fig. 42.

9 MAR 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Equivalent Reflection Height in Kilometers

Longport, New Jersey

20 January 1944

Equivalent Reflection Height vs. Time of Day

Longport, New Jersey

21 January 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Equivalent Reflection Height vs. Time of Day

Longport, New Jersey

21 January 1944

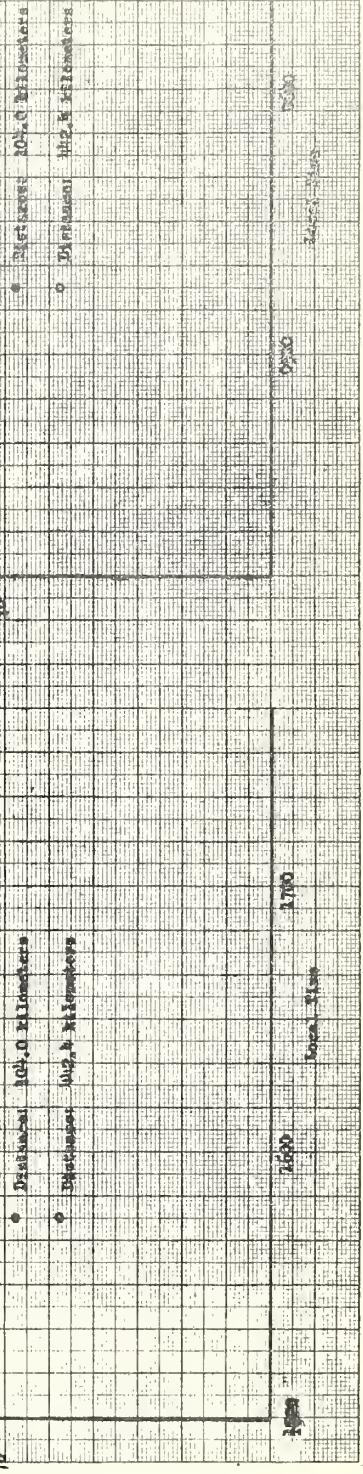
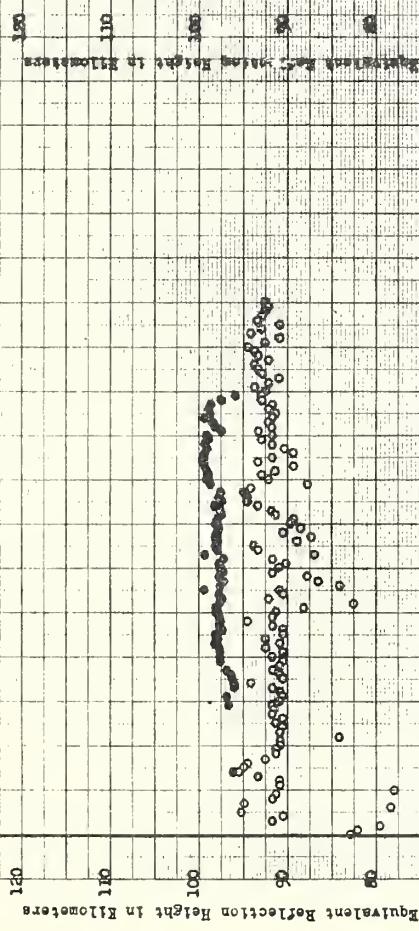


Fig. 45.

9 MAR 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Pauline Reflection, Height vs. Time of Day
Longport, New Jersey
20 January 1944

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Equivalent Reflection Height vs. Time of Day
Longport, New Jersey
22 January 1944

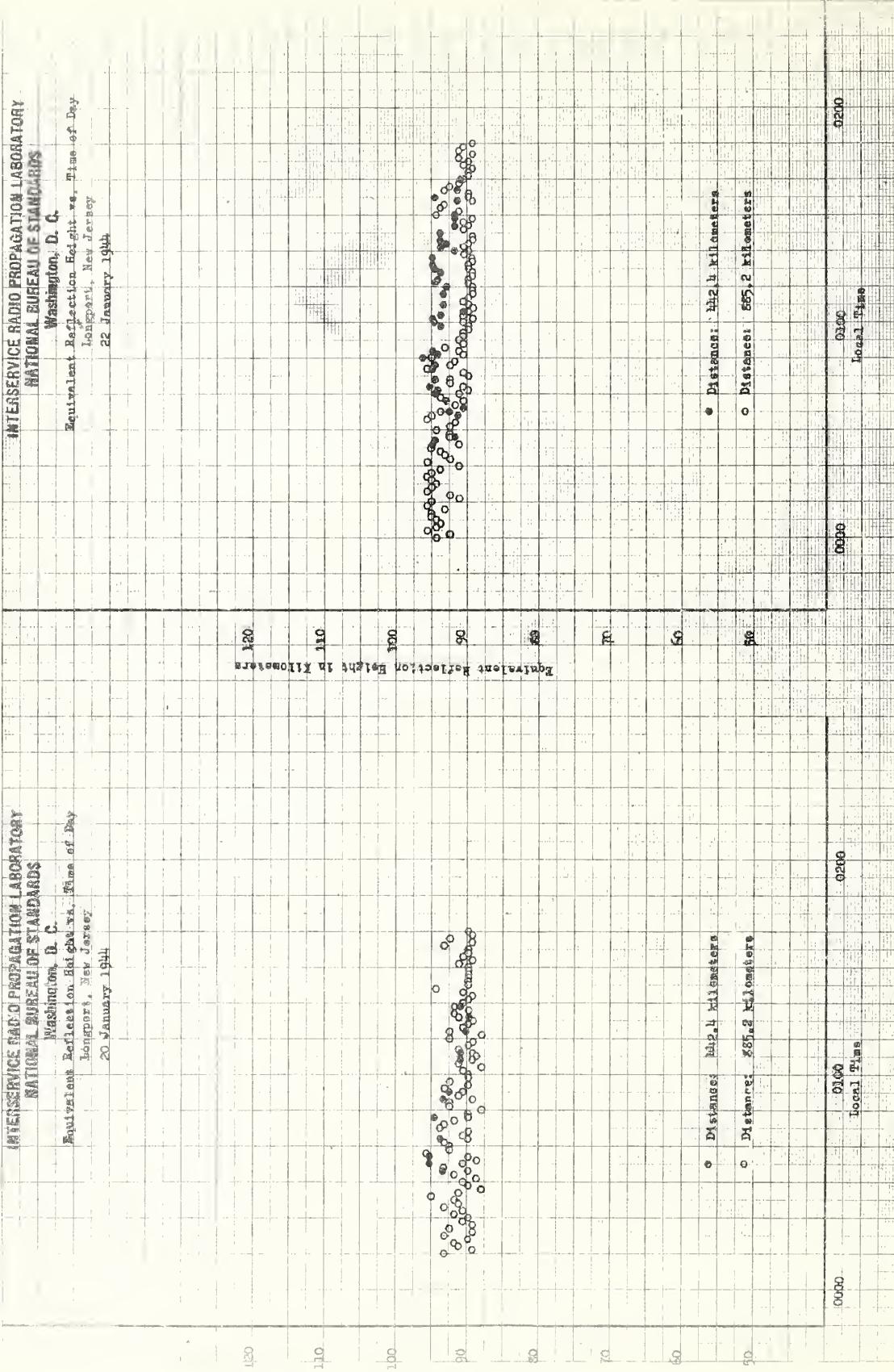


Fig. 46.

INTERSERVICE RADIO PROPAGATION LABORATORY

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Day Time Equivalent Reflection.

Height to Distance

8 December 1943 to 22 January 1944

0900 to 1500 Local Time

Frequency: 1,950 kilocycles

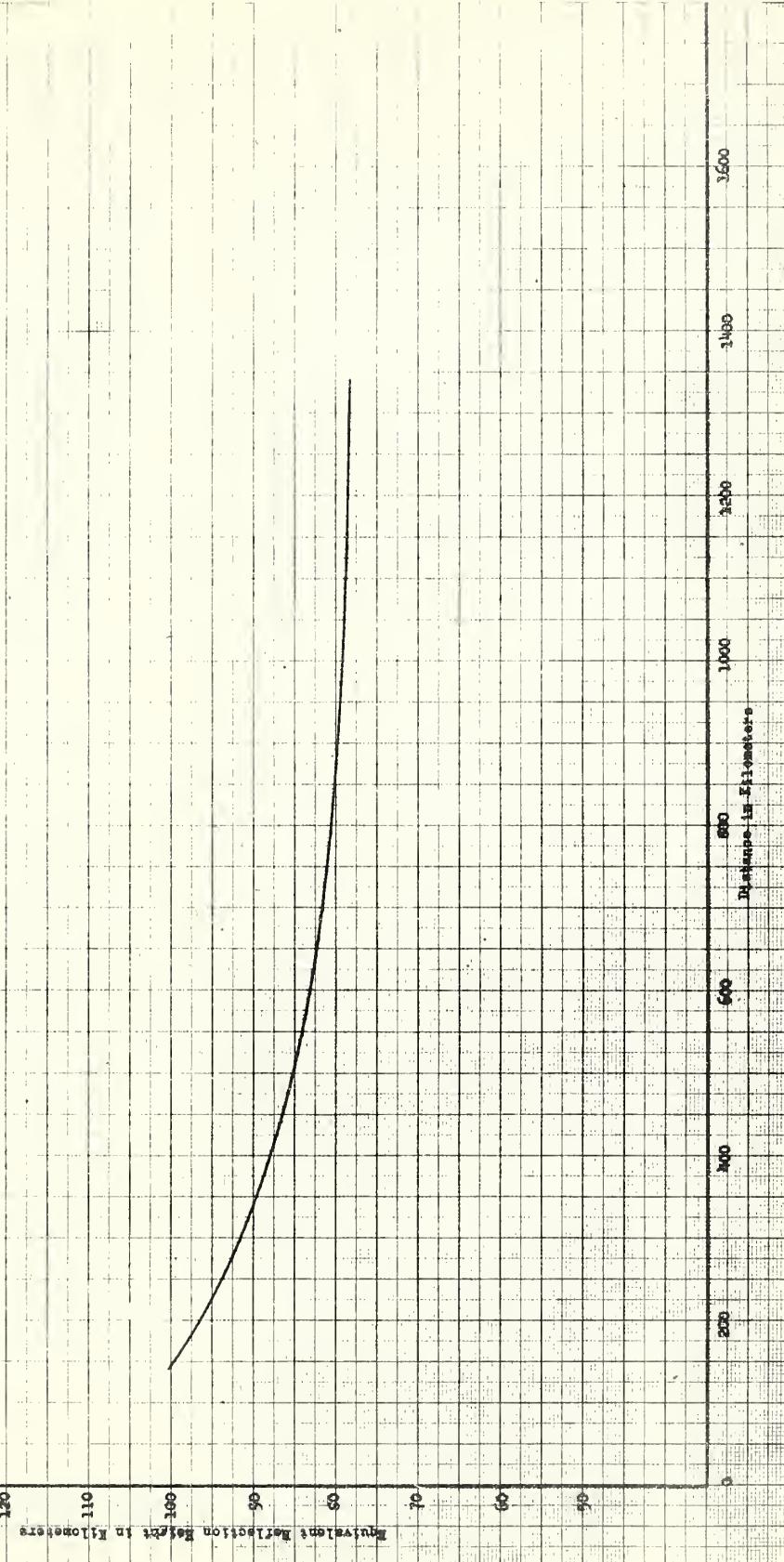


Fig. 47

25 MAR 1944

WIRELESS RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS
Washington, D. C.

Height Fins Equivalent Refraction

Height vs Distance

28 December 1943 to 22 January 1944

2100 to 0300 local Time

Frequency: 1,950 kilocycles

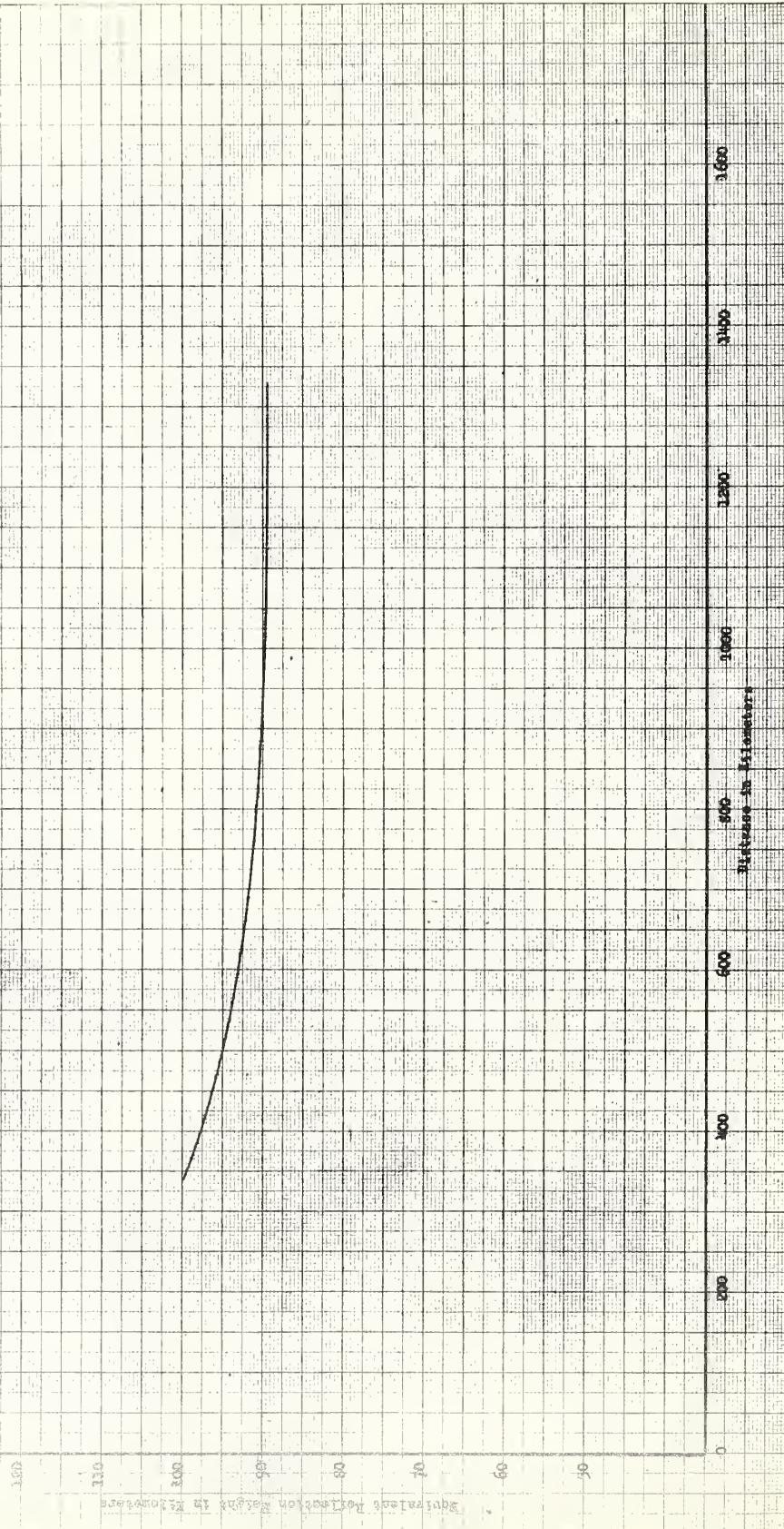


Fig. 48.

INTER-SERVICE RADIO PROPAGATION LABORATORY
NATIONAL BUREAU OF STANDARDS

25 MAR 1944

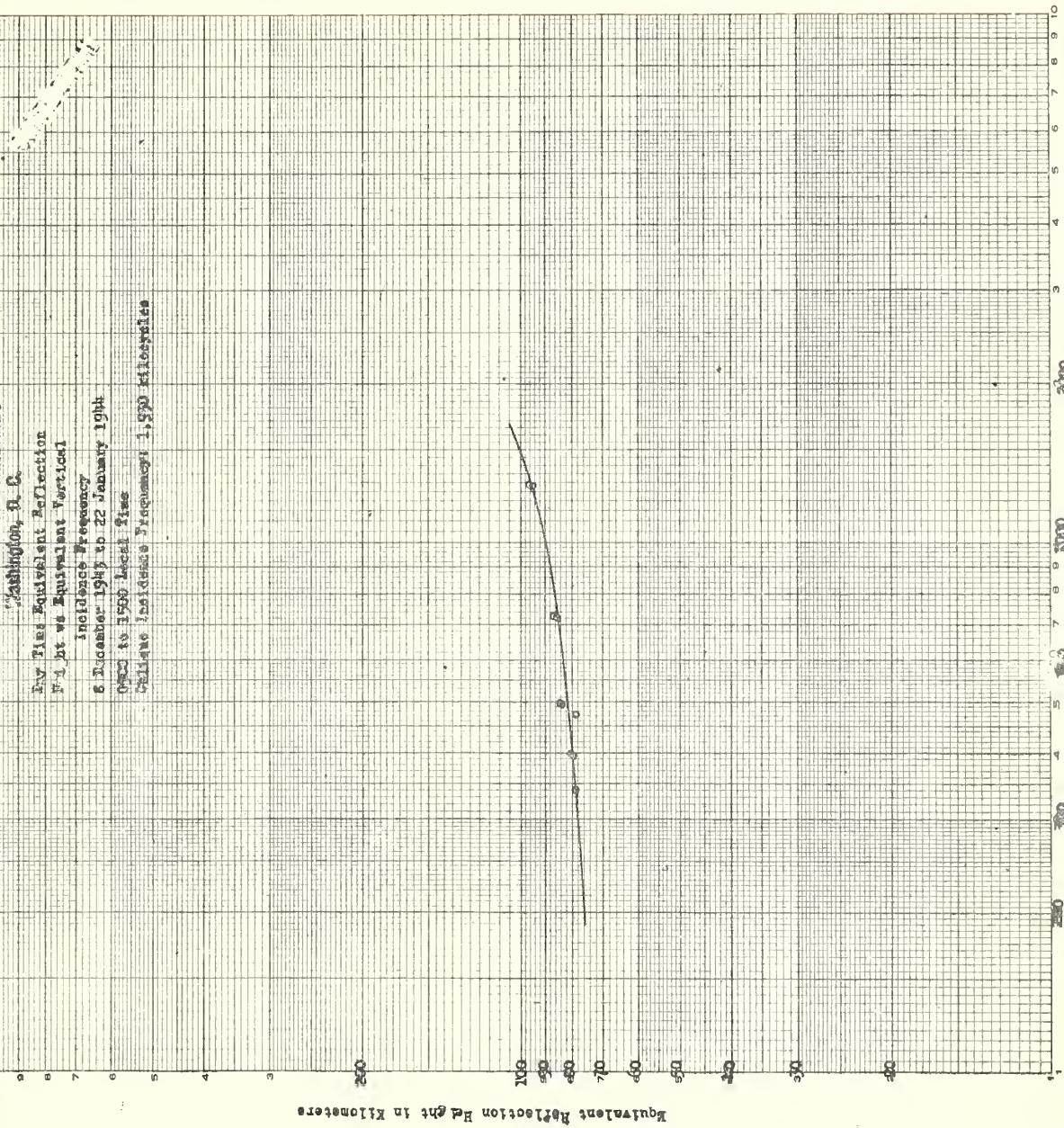


Fig. 50. Equivalent Vertical Incidence Frequency in Kilocycles

Fig. 50.

INTERSERVICE RADIO PROPAGATION LABORATORY

25 MAR 1944

NATIONAL BUREAU OF STANDARDS

Washington, D. C.

Night Time Equivalent Reflection

Height vs Equivalent Vertical

Incidence Frequency

28 December 1943 to 22 February 1944

2100 to 0100 Local Time

Orbital Incidence Frequency: 660

Kilocycles and 1,950 Kilocycles

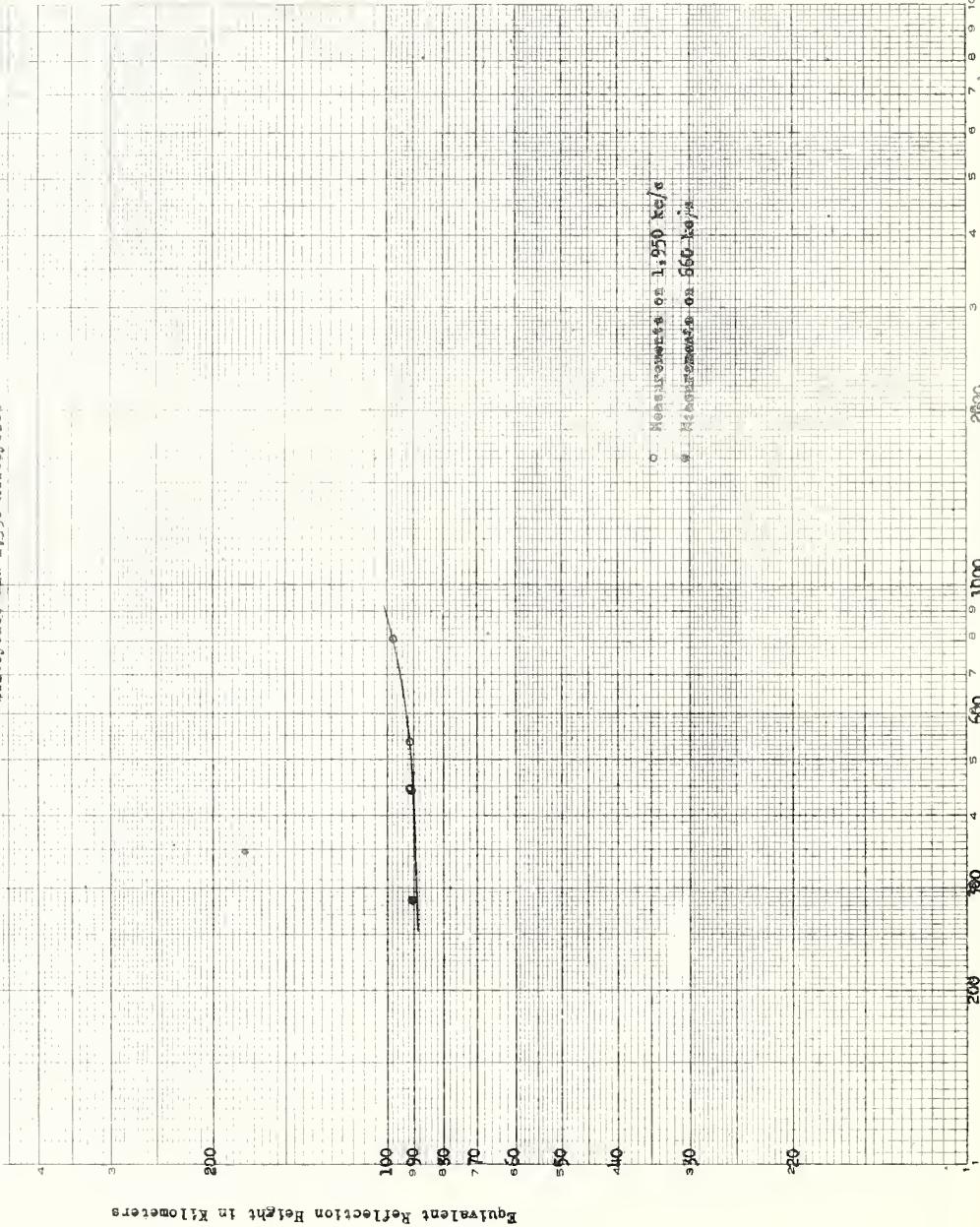


Fig. 51.

